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ART. XLVIII.—*On the Crystallization of Native Copper;* by EDWARD S. DANA. With Plates X to XIII.

Literature.

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Historical summary.—The early writers give but little information about the crystallization of native copper. Haüy, and Mohs (1822) figure only the simple crystals showing the combination of the cube, octahedron and dodecahedron. Haüy, however, speaks of a crystal consisting of a low hexagonal pyramid with a short hexagonal prism, which seems to be the same form described by Haidinger in 1824. This latter crystal was from the Nalsö, and showed the tetrahexahedron *e* (210, *i*-2) shortened in the direction of an octahedral axis and probably twinned parallel to the octahedral plane normal to this axis (compare figures 20, 21, Plate XI).

The first important contribution to the subject is that of Rose in 1837. He added to the planes before observed the tetrahexahedron *k* (520, i-$\frac{5}{2}$) and trisoctahedron *m* (311, 3-3), both on crystals from the Ural. He also gives an interesting description and explanation of the complex crystalline growths afforded by the Siberian mines. He shows that in these forms the branching takes place in the direction of the edges of an octahedral face, that is, at angles of 60°, while the upper and lower parts of the plates are in twinning position to each other. The whole growth consequently forms a single twin, in which the twinning-plane is the octahedral plane in which the branches extend. Rose gives two large figures, projections upon the octahedral twinning-plane which show clearly the ideal relations of the parts of these complex forms.

Lévy about the same time (1837) described twin crystals with *e* alone, and also with *a*, *d*, *o* and *e*; he also mentions the pseudo-hexagonal forms resulting from the distortion and twinning of the tetrahexahedron *e*. Haidinger in 1863 described peculiar hexagonal twins from Burra-Burra in Australia, formed by a combination of the dodecahedron and cube. Schrauf in 1872 gave further obervations of the Australian copper, describing pentagonal dodecahedrons of the form *e*. In 1873 the same writer figured a twin crystal of artificial copper in which *m* (311, 3-3) was prominent. Zerrenner in 1874 mentioned a crystal from Bolivia with *e* and *t* (421, 4-2), but gave no measurements to support the latter form.

Seligmann in 1876 described crystals from the Friedrichssegen mine in Nassau showing pseudohexagonal symmetry, and also twins with orthorhombic symmetry, not unlike forms from Lake Superior explained on a later page. Jérémejew in 1877 described crystals from the Altai with the form *f* (310, i-3). G. vom Rath in 1877 gave an interesting account of some Lake Superior crystals with the new hexoctahedron *y* (18·10·5, $\frac{18}{5}$-$\frac{9}{5}$); also of a complex combination of this form with the tetrahexahedron *k*, showing a secondary growth of the first form on the second. He gave, too, a brief account of a dendritic crystalline growth analogous to the forms described by Rose.

Fletcher in 1880 added the following new forms: *h* (410, i-4), *ε* (730, i-$\frac{7}{3}$), *δ* (740, i-$\frac{7}{4}$), *l* (530, i-$\frac{5}{3}$), *ω* (511, 5-5), *μ* (411, 4-4), and *v* (531, 5-$\frac{5}{3}$). Of these, Lake Superior specimens yielded all except *δ* and *ω*. Lasaulx in 1882 described twin crystals of copper from the Ohligerzug mine near Daaden, on the Sieg. They were polysynthetic octahedral twins, in part with enclosed twinning lamellæ, and in part star-shaped, formed by the grouping of five octahedral crystals about a common center. A form similar to that last mentioned was described in 1883 by Foullon; it was from Schneeberg, in Saxony. The most

recent contribution to the subject in hand is that by W. G. Brown in the last number of this Journal. The crystals described by him were artificial and showed some interesting peculiarities of twinning structure.

The list of forms thus identified upon crystals of native copper is as follows:

Cube a (100, i-i), dodecahedron d (110, i), octahedron o (111, 1); tetrahexahedrons h (410, i-4), f (310, i-3), k (520, i-$\frac{5}{2}$), ε (730, i-$\frac{7}{3}$), e (210, i-2), δ (740, i-$\frac{7}{4}$), l (530, i $\frac{5}{3}$); trisoctahedrons ω (511, 5-5), μ (411, 4-4), m (311, 3-3); hexoctahedrons t (421, 4-2)?, y (18·10·5, $\frac{18}{5}$-$\frac{9}{5}$), v (531, 5 $\frac{5}{3}$).

Through the kindness of Mr. Clarence S. Bement of Philadelphia, the writer has had an opportunity to make a careful study of his beautiful collection of specimens of native copper from Lake Superior, numbering upwards of sixty. A considerable part of these were collected by Mr. Norman Spang, whose exceptional opportunities in this direction, extending over a number of years, were most zealously used; to these Mr. Bement has himself made many important additions. It is not too much to say that these specimens taken together form the finest collection ever made of the crystallized native copper from this remarkable locality, while many of the individual specimens are wholly unique. As will be seen from the descriptions in the following pages the collection offers many points of scientific interest and novelty. In addition to this suite of specimens and a few others from foreign localities, the writer has also had the use of a large number belonging to the cabinets of Professor G. J. Brush and of the Yale College Museum. These have served in some important respects to supplement the Bement collection.

List of planes observed.—The planes which have been observed on the specimens named are: a, d, o; tetrahexahedrons h, k, e, l; trisoctahedrons m, n (211, 2-2); hexoctahedrons y, x (11·6·1, 11-$\frac{11}{6}$), z (12·3·2, 6-4)?. Of these n, x, z are new to the species.

Description of simple forms.—Figures 1 to 12, on Plate X, show the more important of the simple forms in their normal symmetrical development, which have been observed on the Lake Superior specimens. Decidedly the most common type is that of the tetrahexahedrons, and of the four included in the above list h and k occur most frequently, especially the former. This form h (410, i-4) is shown alone in fig. 4; it is the most obtuse of the tetrahexahedrons observed on this species and thus approximates most nearly to the cube; its interfacial angles (supplement) are: over a=28° 4′, over d=61° 56′, and over the edge A (410∧401)=19° 45′. Fig. 6 on the other hand gives the tetrahexahedron l (530, i-$\frac{5}{3}$), which approaches

nearest to the dodecahedron, it is interesting to note that its angles over *a* and *d* respectively are the same as those of *h* over *d* and *a*. The form *h* is usually combined with the cube (fig. 5) or with the cube, dodecahedron and octahedron (fig. 7); not infrequently *h* and *k* appear together both beveling the cubic edges (fig. 8). In fig. 9 we have the dodecahedron modified by the planes of this same tetrahexahedron. The faces of *h* are commonly striated in a direction normal to the cubic edges owing to an oscillatory combination of the planes of a hexoctahedron which, as noted later, has probably the symbol 12·3·2 (6 4). Not unfrequently, however, the faces of *h* are smooth and free from striations. The form *k* also occasionally shows similar striations.

Of the primary forms of the system, the cube alone is a rather common occurrence, and the dodecahedron occurs though less frequently. The octahedron by itself, however, is not represented at all on the specimens in hand; this may be due in part to accident but seems to show that the octahedral form alone is at any rate much less common than is the case with the other isometric native metals. Fig. 1 gives the nearest approach to the simple octahedron observed, and in fig. 11 the octahedron is shown modified by the hexoctahedron *y*. The octahedron is also prominent in the complex crystalline growth shown in fig. 48.

Fig. 2 represents the only case in which the trisoctahedron *m* (311, 3 3) was observed; this, as will be remembered, is a very common form with gold. Fig. 3 shows a combination, which will be recognized at once as the common garnet form, it is, however, very rare with this species and is only represented by one specimen. The faces of the trisoctahedron are slightly uneven with the tendency to striation common with the species, and hence no exact measurements were possible. The true symbol is obvious, however, since these faces truncate the edges of the dodecahedron; strictly it should perhaps be said that the symbol 211 (2-2) is the one toward which the form closely approximates.

Fig. 10 illustrates a type of crystal represented by several specimens and similar to that described by vom Rath; it is a dodecahedron with the planes of the hexoctahedron *y* (18·10·5, $\frac{18}{5}$·$\frac{9}{5}$). This symbol was assigned by vom Rath with some question, as his measurements were not very precise, but the writer's observations go to confirm his conclusion. The angles of the hexoctahedron are as follows:

Edge *A*.	Edge *B*.	Edge *C*.
18·10·5 ∧ 18·5·10	18·10·5 ∧ 18·10·$\bar{5}$	18·10·5 ∧ 10·18·5
19° 12½′	27° 17$\frac{5}{8}$′	30° 58′

Also

100 ∧ 18·10·5=31° 50¾′, 110 ∧ 18·10·5=20° 52½′, 111 ∧ 18·10·5=36° 44½′.

The only one of the above angles which could be measured with really satisfactory precision was the inclination of two opposite faces on the dodecahedral plane; these were found to be 20° 59′ and 21° 0′, which correspond very closely with the calculated angle 20° 52⅔′. Also for 18·10·5 ∧ 18·5·10 was obtained 19° 14′, required 19° 12½′. On two of the specimens the faces of this hexoctahedron were striated coarsely parallel to the edge *C*, owing to the oscillatory combination of this form with a second hexoctahedron approximating closely in position to it. It was not possible to obtain a reliable symbol for the second form.

Another hexoctahedron is shown in fig. 12, which approximates closely to the dodecahedron. Many of the crystals on the specimen giving this combination showed the dodecahedral faces simply divided by faint striations into four fields. Other crystals showed the hexoctahedron distinct, two faces, over the tetrahexahedral edge (*B*), being in oscillatory combination and hence producing a fine striation. In one or two cases the faces were large and smooth enough to yield distinct images with the compound goniometer, and in this way were obtained

$$11{\cdot}6{\cdot}1 \wedge 11{\cdot}1{\cdot}6 = 33^\circ\ 12' \quad \text{and} \quad 11{\cdot}6{\cdot}1 \wedge 11{\cdot}6{\cdot}\bar{1} = 9^\circ\ 15'.$$

The various angles for 11·6·1 or 11·$\frac{1}{6}$·1 are:

Edge *A*.	Edge *B*.	Edge *C*.
11·6·1 ∧ 11·1·6	11·6·1 ∧ 11·6·$\bar{1}$	11·6·1 ∧ 6·11·1
32° 40⅓′	9° 7½′	32° 40⅓′

Also

$$100 \wedge 11{\cdot}6{\cdot}1 = 28^\circ\ 56\tfrac{1}{2}', \quad 110 \wedge 11{\cdot}6{\cdot}1 = 16^\circ\ 59\tfrac{1}{4}', \quad 111 \wedge 11{\cdot}6{\cdot}1 = 34^\circ\ 14'.$$

The agreement is close enough to establish the symbol given as at least representing very closely the position of the form in question. Some of the crystals of this specimen showed the cube also as a prominent form.

Still another hexoctahedron is exhibited by the twin crystal figured on Plate XI (fig. 32). This form is interesting because it is clearly the one whose oscillatory combination produces the fine striation often observed on the faces of the tetrahexahedron *h*. This fact fixes the ratio of two of the axes as 4 : 1 and the measured angle on *a*, the only one obtainable with anything like accuracy serves to establish as the probable symbol 12·3·2 (6·4), which, however, needs confirmation.

$100 \wedge 12{\cdot}3{\cdot}2 = 16^\circ\ 43\frac{1}{2}'$ calculated, $= 16^\circ\ 30'$ measured. The principal angles for this form are:

Edge *A*.	Edge *B*.	Edge *C*.
12·3·2 ∧ 12·2·3	12·3·2 ∧ 12·3·$\bar{2}$	12·3·2 ∧ 3·12·2
6° 28¼′	18° 22⅙′	60° 18½′.

A number of the specimens showed more or less indistinctly planes of one or more hexoctahedrons, but it was only rarely

that it was possible to obtain measurements accurate enough to admit of their determination. The question as to whether they were to be identified with already known forms had usually to be left undecided.

Irregularities of structure of the simple forms.—Native copper is like gold in the frequency with which its crystals show hollow and cavernous forms and other related peculiarities of structure. One specimen consists of a group of simple dodecahedrons, the faces of which show deep irregular cavities. In another the forms are hardly more than skeletons, the crystal, although nearly perfect, being in fact a mere shell. In other cases the edges of the crystal were salient and the faces deeply depressed. One example is given in fig. 15 where the cubic face is depressed, the sides of the depression being taken by the dodecahedral planes. The faces of the cubic planes especially are often thickly covered with quadrilateral pits formed by the dodecahedral planes (fig. 15) or by those of one of the common tetrahexahedrons. Striated faces and faces with wavy irregular surface are also frequently observed. Other irregularities, sometimes of an accidental nature, might be mentioned.

It is also common to observe cases of more or less distinct and regular elevations, triangular or quadrilateral or hexagonal, upon the larger faces. Sometimes these can be referred to known forms, but in others they are too indistinct to be determined. A vicinal tetrahexahedron on the cubic faces is occasionally noted. A prominent example of distinct and regular elevations is given in fig. 13, where at the extremities of the cubic axes there are the projecting pyramids formed by the faces of the tetrahexahedron l (530, i-$\frac{5}{3}$), a form which, as already stated, bears a peculiar relation to h.

Figure 13 also illustrates another point in the peculiarities of crystalline structure. One angle of the cube is here cut off by a broad octahedral face, at the center of which the planes of the tetrahexahedron h appear forming a small six-sided pyramid. Other crystals show the same thing in greater or less symmetry of development, sometimes several of the octahedral angles being treated in the same way. The octahedral face may be made up of a series of plates with parallel edges, upon which a number of minute pyramids are present, formed in the same way. This peculiarity is interesting because it introduces us to a point immediately to be considered, the tendency of the crystals to develop with rhombohedral symmetry. Thus a number of specimens consist essentially of flattened plates, corresponding to an octahedral plane, whose surfaces are covered with six-sided tabular and pyramidal elevations, the latter often very small and thickly crowded together. These pyramids are always formed by the six planes of a tetrahexahedron, which

meet at the extremity of an octahedral axis. When the tetrahexahedron is the form h, the angles (supplement) of the scalenohedral pyramid are 61° 56′ and 19° 45′, while the angles at the base of the pyramid are 87° 55′ and 152° 12′ respectively. This is shown in fig. 14. When, however, the elevations are formed by planes of the tetrahexahedron e (210, i-2), the pyramid is a regular hexagonal pyramid with a pyramidal angle of 36° 52′, and each of the angles at the base is 120°; the latter is more common; it is illustrated in fig. 52.

A secondary growth over an original crystal is sometimes observed. One remarkably symmetrical case of this has been already spoken of as described by vom Rath. Usually the result is to partially obliterate the original form. Thus in one specimen the crystals show numerous tuberose sproutings, suggestive of a fungus growth; in another two large dodecahedral crystals are partially enclosed, each by a rough mass of copper showing only a trace of crystalline form.

Distorted forms and those showing pseudo-symmetry.—Cases showing irregular distortion are common, but among the simple crystals hardly more so than is the case with many other crystallized species. The distortion, on the contrary, usually exhibits a certain degree of regularity, being in the direction of one of the inter-axes of the crystal and thus giving rise to forms with marked pseudo-symmetry. Elongation in the direction of a cubic axis is frequently observed and where symmetrical, produces pseudo-tetragonal forms as shown in fig. 16; compare also figures 48 and 49 described later. Where the elongation is in the direction of one extremity of a cubic axis the forms are hemimorphic in type and more or less irregular.

A symmetrical development of a crystal about an octahedral axis gives rise to forms with rhombohedral pseudo-symmetry and these cases are so frequent and interesting that they are described at length below. Elongated wire- and band-like forms of varied shape, often much curved and twisted, and showing some crystalline markings on the surface, are common but these forms are generally very indistinct, and are hardly to be spoken of as crystals.

Crystals with rhombohedral symmetry.—It is an interesting fact in connection with the crystallization of the native metals, gold, silver and copper, that they so often show a tendency to develop with rhombohedral instead of isometric symmetry. Many cases of this kind have been noted; one striking example has been recently described by the writer,* in which crystals of native gold had essentially the form of an acute rhombohedron ($4R$); these were arranged in parallel position so as to form slender strings of rhombohedrons developed in the direc-

* This Journal, xxxii, 132, August, 1886.

tion of a trigonal axis of the trisoctahedron (3-3), the other planes of the trisoctahedron forming a pyramid $\frac{4}{3}$-2 and obtuse rhombohedron $\frac{2}{3}R$.

Frequent examples of this tendency have been observed among the specimens of copper under examination, though none so marked as that just mentioned. The following list includes some of the common forms of the isometric system with the symbols that belong to them when placed with an octahedral axis (normal to 111) vertical, taking the cube with a rhombohedral angle of 90° as the unit form. The vertical axis is then c=1·22474.

	Isometric.			Rhombohedral.	
Cube	a O,	100,	a	$10\bar{1}1$,	R
Octahedron	1,	111,	o	0001,	O
		$11\bar{1}$,	$o_{,}$	$02\bar{2}1$,	$-2R$
Dodecahedron	i,	110,	d	$01\bar{1}2$,	$-\frac{1}{2}R$
		$10\bar{1}$,	$d_{,}$	$11\bar{2}0$,	i-2
Trisoctahedrons	2-2,	211,	p	$10\bar{1}4$,	$\frac{1}{4}R$
		$11\bar{2}$,	$p_{,}$	$10\bar{1}0$,	∞R
		$21\bar{1}$,	$p_{,,}$	$12\bar{3}2$,	$-\frac{3}{4}$-$\frac{3}{2}$ or $-\frac{1}{2}$ [3]
	3-3,	311,	m	$20\bar{2}5$,	$\frac{2}{5}R$
		$31\bar{1}$,	$m_{,}$	$22\bar{4}3$,	$\frac{4}{3}$-2
		$3\bar{1}1$,	$m_{,,}$	$40\bar{4}1$,	$4R$
Tetrahexahedrons	i-2,	210,	e	$11\bar{2}3$,	$\frac{3}{2}$-2
		$20\bar{1}$,	$e_{,}$	$21\bar{3}1$,	3-$\frac{3}{2}$ or 1 [3]
	i-$\frac{5}{3}$,	530,	l	$23\bar{5}8$,	$-\frac{8}{5}$-$\frac{5}{3}$ or $-\frac{1}{3}$ [5]
		$50\bar{3}$,	$l_{,}$	$53\bar{5}2$,	4-$\frac{5}{3}$ 1 [4]
	i-$\frac{5}{2}$,	520,	k	$32\bar{5}7$,	$\frac{6}{7}$-$\frac{5}{4}$ or $\frac{1}{7}$ [6]
		$50\bar{2}$,	$k_{,}$	$52\bar{7}3$,	$\frac{7}{3}$-$\frac{7}{5}$ $1\frac{2}{3}$ [7]
	i-4	410,	h	$31\bar{4}5$,	$\frac{4}{3}$-$\frac{4}{5}$ or $\frac{2}{3}$ [8]
		$40\bar{1}$,	$h_{,}$	$41\bar{5}3$,	$\frac{5}{3}$-$\frac{5}{4}$ $1\frac{1}{3}$ [9]

Among the specimens of native copper two showed rather distinctly the acute rhombohedral form ($-2R$) of fig. 17. The rhombohedral angle is here 70° 32′ and the plane facial angle 60° at the summit. The basal plane which is needed to fill out the eight faces of the normal octahedron was not distinctly present, and in fact the crystals were all lacking in sharpness, though there seems to be no doubt about the interpretation of the form.

Another specimen (fig. 18) showed a long hexagonal prism i-2 ($d_{,}$) terminated by an obtuse rhombohedron $-\frac{1}{2}R$ (d), with also subordinate planes of the rhombohedrons R(a), $-2R$($o_{,}$); in a normal isometric crystal this would be simply a combination of dodecahedron, cube and octahedron. A basal projection (fig. 23) shows the rhombohedral symmetry very clearly. The tetrahexahedron e (210, i-2) is frequently developed according

to rhombohedral symmetry, as was early noted by Haüy (see above, p. 413), Haidinger, Lévy and others. As shown in the above list it then corresponds to a hexagonal pyramid of the second or diametral series ($\frac{2}{3}$-2) and a scalenohedron 1^{3}. The twelve planes of the latter form are often subordinate or nearly absent, and the result is then the pyramid shown in fig. 21; it is this pyramid which, as remarked before, so often covers the surface of broad octahedral plates. In such a form as fig. 21 there is nothing to indicate whether we are dealing with a simple crystal or a twin. If two opposite pairs of these planes are extended the result is an orthorhombic prism terminated by an obtuse pyramid.

Various more or less complex rhombohedral forms occur according as the planes just mentioned are modified by the faces of the cube, dodecahedron or octahedron. Thus in fig. 20 we have the planes of three of these forms together; this represents a simple crystal such as has been repeatedly observed, although twins of similar habit also occur.

One interesting crystal was observed which was a rhombohedral penetration-twin of the tetrahexahedron i-$\frac{5}{3}$ (530) and cube. Of the faces of the first mentioned form the twelve, comprising in the rhombohedral position the negative scalenohedron $-\frac{5}{6}$, were prominent, those of the other scalenohedron indistinct; the cubic faces were all present, six above and six below. The twinning plane was the basal (octahedral) plane. The other tetrahexahedrons i-4 and i-$\frac{5}{2}$ are also developed at times, more or less distinctly, after the rhombohedral type, especially the former. The scalenohedron $\frac{2}{5}$ forms common six-sided elevations on the octahedral plates, as shown in fig. 14 already alluded to.

Twin crystals.—The specimens of native copper from Lake Superior occur very frequently in twin crystals, although the remark of Rose in regard to the Siberian specimens that simple crystals are rare would not be true of those under examination. The law of twinning is always the same—the twinning-plane a face of the octahedron—but the variety and complexity of these twinned crystals is truly remarkable. The twins are with very rare exceptions contact twins; a few penetration twins have been observed, as also a few cases of repeated twinning.

A penetration-twin of rhombohedral type, with l (530, i-$\frac{5}{3}$) as the predominating form has been spoken of in a preceding paragraph. Another interesting case is shown in fig. 26. The predominating form is the tetrahexahedron k, though the allied form h occurs subordinate, and the octahedron and dodecahedron are both present. From one point of view the crystal

appears as a nearly symmetrical cruciform twin, while looking down upon the central octahedral face (as in fig. 26) the habit is rhombohedral. It appears at first sight to be a compound twin but the three octahedral faces in twinning position may all be referred to the same individual; the symmetry of the crystal is nearly equal to that of the drawing.

Figure 22 shows a simple contact twin of the cubo-tetrahexahedron with the usual re-entering angles; this is similar to the forms figured by Lévy. Contact twins of simple habit and normal development are very rare. Octahedral twins of the spinel type have been noted only in a complex growth similar to that represented in fig. 54, and described later.

The spinel law applied to the cube yields the form represented in fig. 25. This is the common type of twins among the Siberian specimens as noted by Rose. Among those from Lake Superior, however, crystals of exactly this form are very rare. Almost invariably, these cubic twins are shortened in the direction of the twinning axis, thus yielding a form consisting of two similar triangular pyramids placed base to base. This form, noted by Sadebeck,* on the native silver from Kongsberg, is represented in fig. 24, and again in fig. 27, the latter in the orthorhombic position as mentioned below. These triangular twin crystals have a most anomalous appearance when they occur alone, suggesting a tetrahedron, or a hemitetragonal trisoctahedron, at first sight. One specimen from the cabinet of Professor Brush shows a broad surface of copper thickly sprinkled with very minute forms (1^{mm} to $\frac{1}{4}^{mm}$), some of them cubes, others tetrahexahedrons; and not a few are these triangular twins, like fig. 24 or fig. 31, and usually implanted by an acute trihedral angle.

Cases are rare, however, in which these cubic forms appear with this normal development. Generally they are elongated in a direction of a diagonal of the octahedral twinning-face and thus assume the symmetry of a (hemimorphic) orthorhombic crystal. Figure 27 shows this twin in the position corresponding to the latter symmetry. As this method of development is so common it is interesting to note the symbols of the common isometric forms when so placed. Accepting as the fundamental or unit pyramid, two of the cubic faces (100 and 010), the angles of this pyramid are 90° (brachydiagonal edge), and 70° 32′ (front or macro-edge formed by twinning). The plane angle at the summit is 45°. The orthorhombic axes are accordingly:

$$\breve{a} : \breve{b} : \dot{c} = 0{\cdot}8165 : 1 : 1{\cdot}4142$$

The direction of the vertical axis coincides with a diagonal of the octahedral twinning-plane, that of the brachydiagonal

* Min. petr. Mitth., i, 295, 1883.

axis with the edge of the plane normal to this diagonal, and that of the macrodiagonal axis is the twinning-axis, normal to the twinning-plane.

With respect to these axes the isometric forms met with on these copper twins group themselves as in the following table; the different forms into which the single isometric form separates are indicated, as in the preceding table, by subscript accents.

	Isometric.	Ortho-rhombic.		Isometric.	Ortho-rhombic.
Cube	a 100	111	Octahedron	111	014
	010	$\bar{1}11$	o	$1\bar{1}1$	$01\bar{4}$
	a_1 $00\bar{1}$	$01\bar{2}$		$\bar{1}11$	$\bar{2}12$
			o_I	$\bar{1}\bar{1}1$	212
Dodecahedron	d 110	011		$\bar{1}1\bar{1}$	$21\bar{2}$
	d_1 $1\bar{1}0$	100		$\bar{1}\bar{1}\bar{1}$	$21\bar{2}$
	d_{II} 101	103		$1\bar{1}1$	$0\bar{1}0$
	011	$\bar{1}03$	o_{II}	$11\bar{1}$	010
	d_{III} $10\bar{1}$	$12\bar{1}$			
	$01\bar{1}$	$\bar{1}21$			
	etc.				
Tetrahexahedrons	k 520	377	h	410	355
	k_1 $5\bar{2}0$	733	h_1	$4\bar{1}0$	533
	k_{II} 502	539	h_{II}	401	436
	k_{III} $50\bar{2}$	571	h_{III}	$40\bar{1}$	452
	k_{IV} $20\bar{5}$	$27\bar{8}$	h_{IV}	$10\bar{4}$	$15\bar{7}$
	etc.			etc.	
	e 210	133	e_{II}	201	214
	e_1 $2\bar{1}0$	311	e_{III}	$20\bar{1}$	230
			e_{IV}	$10\bar{2}$	$13\bar{3}$

It will be seen from the table that the brachypinacoid (010, $\dot{i}$-$\bar{i}$), is formed by one of the octahedral planes (o_{II} $11\bar{1}$), the macropinacoid (100, $\dot{i}$-$\bar{i}$) by a dodecahedral plane (d_I, $1\bar{1}0$); also one of the planes of the tetrahexahedron e is a prism (e_{III} $20\bar{1}=230$, $\dot{i}$-$\frac{3}{2}$).

All of the planes given in the above list play an important part in these twins. The transformation from the isometric symbol ($h_1h_2h_3$) to that of the corresponding orthorhombic form ($p_1p_2p_3$) is easily accomplished by aid of the equations:

$$p_1=h_1-h_2 \qquad p_2=h_1+h_2-h_3 \qquad p_3=h_1+h_2+2h_3$$

The way in which these twin crystals are developed will be clear from the following descriptions. One specimen of rare beauty and perfection consists of a group of elongated prismatic forms, the longest about $1\frac{1}{2}$ inches in length. In each of them the extremity is formed by a smooth and symmetrically developed pyramid of the form just described, while the elongation in the direction of the diagonal of the twinning-face is somewhat obscure. Figure 33 represents* one of the

* In the drawing of figures 33, 34, 35, 36, 37, 38, 51, 52, 53, 54, the writer has had the assistance of Mr. J. H. Emerton.

simpler of these forms, as true to nature as possible; figure 35 gives another quite small tapering crystal. In fig. 37 the extremity of a more complex form is represented; here there is a cluster of cubes in parallel position on one side of the form. Other crystals have similar clusters on both sides in their respective twinning positions; they thus serve to reveal the true nature of the terminal pyramid which, taken by itself, might be a serious puzzle, appearing as it does far off from normal isometric forms. The front edge, as seen in fig. 37, is often made up of a series of jagged points formed by a repetition of the lower extremity of the trigonal twin. One of these crystals is so complex a combination of jagged projections on the edges, front and rear and on both lateral edges as to hardly admit of adequate representation.

Another specimen of scarcely less beauty than that just described consists of a group of twin crystals of the same type, but more complex and irregular. In them the common tetrahexahedron h (410, i-4) is prominent, four planes of this form, those about the cubic face 100, namely 410 (h), $4\bar{1}0$ (h_{I}), 401 (h_{II}), $40\bar{1}$ (h_{III}), correspond respectively in the rhombic position to the pyramids 355 ($1\text{-}\frac{5}{3}$), 533 ($\frac{5}{3}\text{-}\frac{5}{3}$), 436 ($\frac{3}{3}\,\frac{4}{3}$) and 452 ($\frac{5}{2}\text{-}\frac{5}{4}$); compare figure 30. Each of these crystals, as is also true of the smaller crystals on the specimen before mentioned, demands a special study before its form can be understood, and this is no easy matter, since exact measurements are out of the question. An adequate illustration of the subject would require an almost indefinite number of ideal as well as artistic figures, since the variety of form is so great.

In fig. 28 the trigonal cubic twin is shown in combination with the octahedron, not an uncommon form, though the crystals of this type are also usually more or less irregularly elongated somewhat as in figures 33, 35 and 37. Figure 31 shows a similar trigonal twin combined with the cube and part of the planes of the tetrahexahedron h; this in the orthorhombic projection appears as in fig. 29. Fig. 30 is another more complex trigonal twin similar to fig. 31, and fig. 32 exhibits the same habit, but instead of the tetrahexahedron we have the hexoctahedron x already described.

Crystals of the type represented in figs. 29 and 30, when developed after the orthorhombic type, form acute, flattened spear-head crystals, as shown in the drawings (figures 36 and 38). In these cases the crystals are flattened in a direction *normal to* the twinning-plane, but in other cases the flattening is parallel to it, as described in the next paragraph. Very frequently on one or both sides some trace of the cube is shown by which the form can be orientated, and not infrequently the tetrahexahedral planes can be seen on the cubic faces in their normal de-

velopment. The front edge is sometimes sharp and jagged in the way described, by the repetition of the lower angle of the trigonal twin. Figure 34 shows this point well; it is drawn (like the simple figure 40) with the twinning-plane parallel to the plane of the paper instead of normal to it, as in all the figures previously spoken of. These simpler specimens often show traces of the complex growth along lines at angles of 60°, and thus pass into such forms as that represented in fig. 51. Other specimens show other forms of the same type, but differing most widely according to the planes present and according to their relative development. In almost all of these the tendency to develop in orthorhombic symmetry is strongly marked.

The tetrahexahedron *e* is an interesting case, since it gives a prismatic form, 230 (i-$\frac{3}{2}$), terminated above and below by a brachy-pyramid 133 (1-$\breve{3}$). This form, which is not an uncommon one, and appears as a spear-head crystal flattened *parallel* to the twinning-plane, is especially noteworthy because it is in this position a normal orthorhombic form, not hemimorphic like the others. The same form may come without twinning from the shortening of the tetrahexahedron in the direction of an octahedral axis and a simultaneous elongation parallel to the middle pair of planes (compare fig. 21 and p. 421).

Another type of twin crystal, somewhat related to those just described, but of very different aspect, is shown in fig. 44. The first crystal studied proved to be a problem of some difficulty, especially as it was very small and only a few planes gave distinct reflections. At first sight it appeared to be a square prism terminated somewhat acutely by an octagonal pyramid and with several small modifying planes. The measurement of a few angles served to unravel the form. The pyramidal angles of two corresponding pairs of planes, measured with fair precision, were found to be

$$38°\ 55' \quad \text{and} \quad 39°\ 7';$$

the angles of the other approximately measured gave

$$30° \quad \text{to} \quad 31°.$$

The first angles given correspond to the angle between two adjacent planes of a twinned octahedron:

$$o \wedge \underline{o} = 38°\ 56'.$$

The other pyramidal angle corresponds to that (30° 27′) between two planes of the tetrahexahedron *k* (520, i-$\frac{5}{2}$). Other angles, measured with more or less accuracy, served to show that the planes present included the cube (*a*), octahedron (*o*), dodecahedron (*d*) and tetrahexahedron *k* (520, i-$\frac{5}{2}$). Figure 44 shows it in ordinary projection, and in fig. 43 a basal projection is

given; the rather close approximation to a tetragonal crystal is obvious at a glance ($o_{II}\ d_I = 90°$).

The same specimen showed other crystals perplexingly like those just described, especially in that they were terminated by a pair of planes looking very similar to the pair of cubic planes in fig. 44. The measured angle between them was, however, about 39° (38° 56′) instead of 70° 32′ (the angle between two cubic faces in twinning position), and they were thus seen to be octahedral faces in twinning position to each other. These forms proved to be the complementary half of the crystal just described, as is shown in fig. 45, which is a projection upon the twinning plane; here both parts, not in fact observed together on the same crystal, are represented together. In fig. 45 the octahedral edge is placed above, to correspond with the symbols given on p. 423. The forms shown in figs. 43–45 are spoken of further in a later paragraph, where the method of grouping (see figs. 46 and 54) is described. The understanding of this type of twin will be facilitated by reference to the simple forms in figs. 39 to 42, all drawn with the twinning-plane parallel to the plane of the paper. Figure 39 is a simple octahedral twin of the spinel type; fig. 40 the trigonal cubic twin already fully described. In fig. 41 the octahedral twin is shown, but much flattened and with the cubic faces on the angles; this is also a copper form. Finally, fig. 42 is the cubic twin with the octahedral faces.

Still another type of twin is represented in fig. 47, which, like those already described, very rarely shows a re-entrant angle. The figure is a projection upon the twinning-plane. The crystals of this type are elongated prisms, one edge formed by two octahedral planes ($o, \wedge \underline{o}, = 38° 56'$) and the other by the pseudo-planes ϑ ($\vartheta \wedge \underline{\vartheta} = 90° 54'$). The figure is placed so as to show the prismatic development, but to understand it, it must be turned so that the plane o_1 is parallel to the same plane in fig. 45; then h and h_{III} correspond to the tetrahexahedron k and k_{III} present there, etc. The pseudo-planes ϑ and ϑ' are formed by the oscillatory combination of two adjacent tetrahexahedral planes h and h_{III}, etc., and are in fact only a series of fine ridges. Were they real planes the symbol for ϑ would be $81\bar{1}$ (S-8) in the isometric system, or 7·10·7 in the orthorhombic position. Twins of this type are sometimes very regular and symmetrical and again highly irregular, and varying much from the simple prismatic form.

Methods of grouping.—The specimens of native copper very commonly show, instead of an irregular combination of crystals, a grouping in parallel position with sharply defined lines of growth. Two methods of grouping are most common. In

the first the lines of growth (the "tectonic axes" of Sadebeck) of the adjoining crystals or parts of crystals (sub-individuals) are the cubic axes; in the second they are axes inclined 60° to each other and generally coinciding with the diagonals of an octahedral face, that is, the lines normal to its edges and bisecting the facial angles. A third method, quite different from the others, has also been observed.

The first method is common with many isometric species, and is represented here in several different forms. Thus one specimen is made up of small cubes grouped in this way. In another there are several series of octahedrons each having a common vertical axis, and each octahedron made up of many small partial octahedrons (like fig. 1), the whole specimen a wonderfully delicate and beautiful arborescent growth. Figs. 48 and 49 show interesting cases of the same thing. In fig. 48 the predominating forms are the octahedron and dodecahedron, though the terminal crystals are sometimes as complex as fig. 16. On this specimen we have sometimes a long wire with projecting points of small octahedrons; then more complex growths with branchings and rebranchings, and again a close even network of rectangular ribs. In fig. 49 the form involved is the tetrahexahedron *h* (410, *i*-4) and the lines of growth are uniformly the cubic axes; as will be inferred from the figure the specimen is one of much beauty and interest.

The second method of grouping is, however, the more interesting, especially so in that the crystals taking part in it are generally twins. Here the twinning-plane is the plane in which the lines of growth lie and these axes are three lines crossing at 60° and situated as described. The explanation of an analogous method of grouping was given by Rose in his description of the complex growth among the Siberian crystals already spoken of. The Lake Superior specimens differ from the Siberian in that, although the branching is also at 60°, the directions are almost always those of the *diagonals* of the octahedral face, not of the *edges*. This statement is true of all the Lake Superior specimens the writer has had the opportunity to examine with a single exception, while one beautiful specimen from Siberia in Mr. Bement's collection agrees with the description of Rose. It may be noted here that Sadebeck describes both these systems of "tectonic axes" as occurring in the dendritic growths of native silver, and he also mentions having observed the diagonal method of growth himself in copper. The Lake Superior specimen described by vom Rath is stated to have conformed to the method given by Rose.

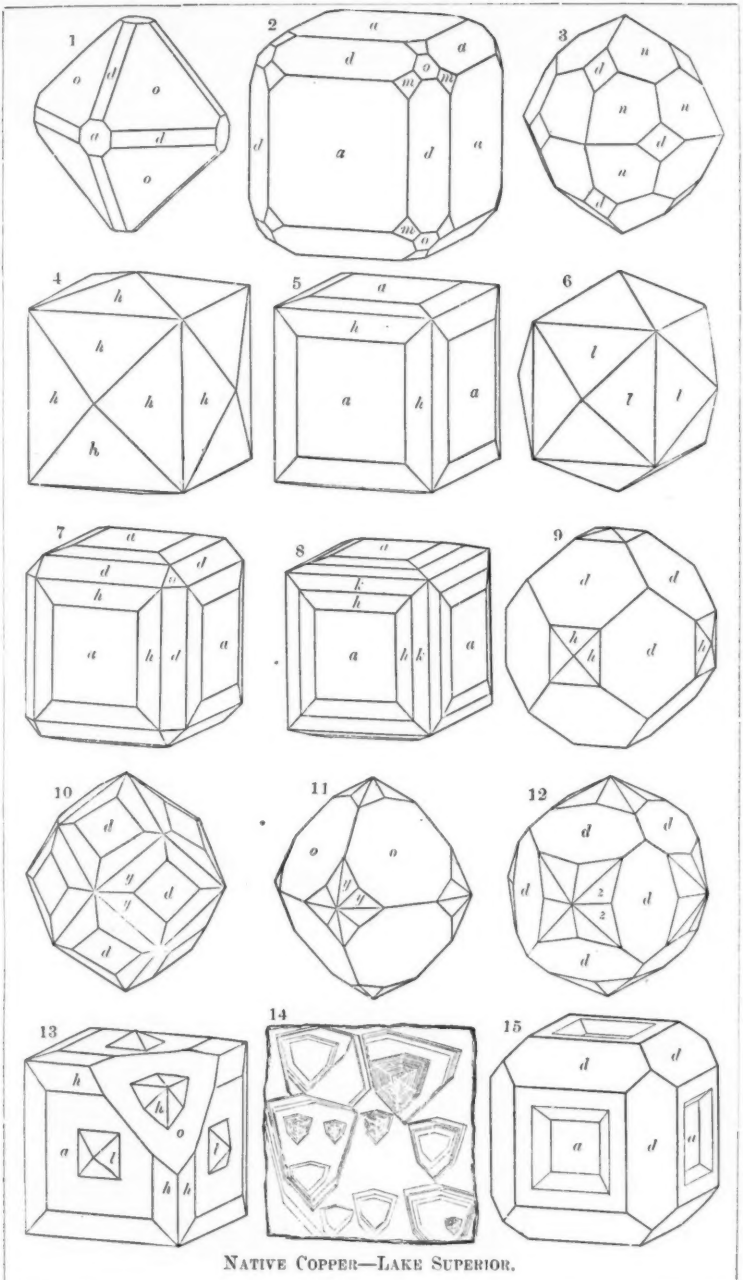
An ideal representation showing the common method of growth spoken of, of the trigonal cubic twins, is given in fig. 50. The actual forms are, however, most complex, for instead

of simple cubes we may have either one of the commoner tetrahexahedrons or a combination of one or more of them with each other or with the cube, octahedron and dodecahedron. Moreover, we have sometimes an open series of cubic twins, and from these we pass to more compact forms and finally to specimens which are simple plates with broad octahedral surface showing the characteristic spear-shaped twins only occasionally at the edges and with the hexagonal lines of growth only slightly accentuated. In the latter cases the octahedral surface is commonly covered over, often very thickly, with hexagonal elevations formed by one of the common tetrahexahedrons as already described. Still further, a number of these branching dendritic growths may be grouped in slightly diverging position about a common center, thus producing arborescent crystallizations of great beauty.

The twinning is also often somewhat complex; for it may be not simply a case of a single twin growth with the upper surface in twinning position with respect to the lower, but on the same side any one of the tectonic axes may be taken by a series of cubic twins in reversed position to those adjoining, or a single crystal in twinning position may appear in the midst of the others.

Fig. 51 represents ($\frac{4}{5}$ths natural size) one of the finest of these remarkable specimens. It illustrates admirably the method of growth and the remarkable complexity of the resulting forms. The spear-head forms at the extremities are here well seen. It is to be noted also, in illustration of a point just made, that for the lower part of the specimen the crystals are in twinning position with reference to the majority of the others, and this is true also of isolated cubes at various other points as at *a*, *a*. Fig. 52 shows one of the tabular forms in which the octahedral plane predominates, and it is only on the central and branching ribs that the other—tetrahexahedral—forms are distinct. The surface is thickly covered with hexagonal plates and low pyramids, which the drawing only in part represents.

In fig. 53 a partially satisfactory representation is given of a very delicate moss-like dendritic crystallization which is especially interesting because careful examination proves that the tectonic axes here are situated diagonally with reference to the common method, in other words it is like the forms figured by Rose. The specimens are nearly an inch in length and very thin and fragile. The octahedral surface is prominent, though cubes in thin plates, or in normal forms, project from it sometimes in one position, sometimes reversed—over one surface there are a number of tetrahexahedrons with rhombohedral (scalenohedral) development implanted on the octahedral surface; these are also in both positions.



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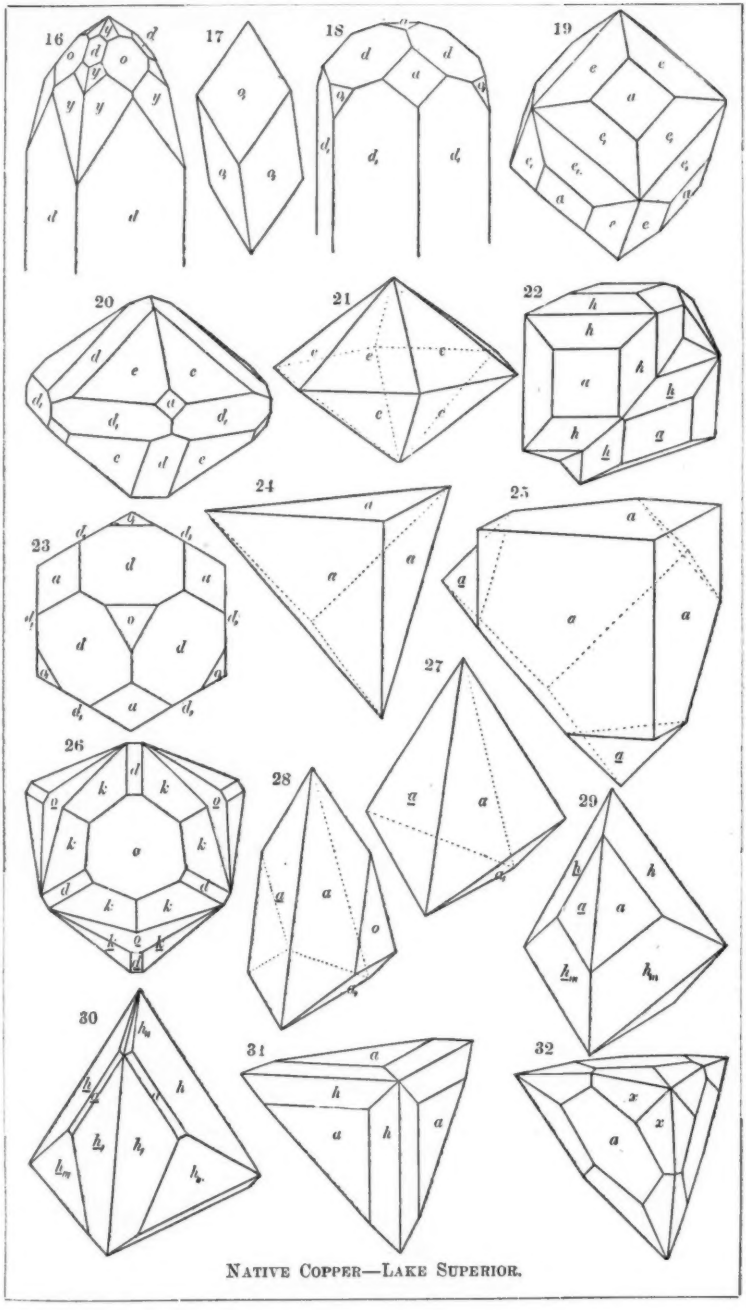

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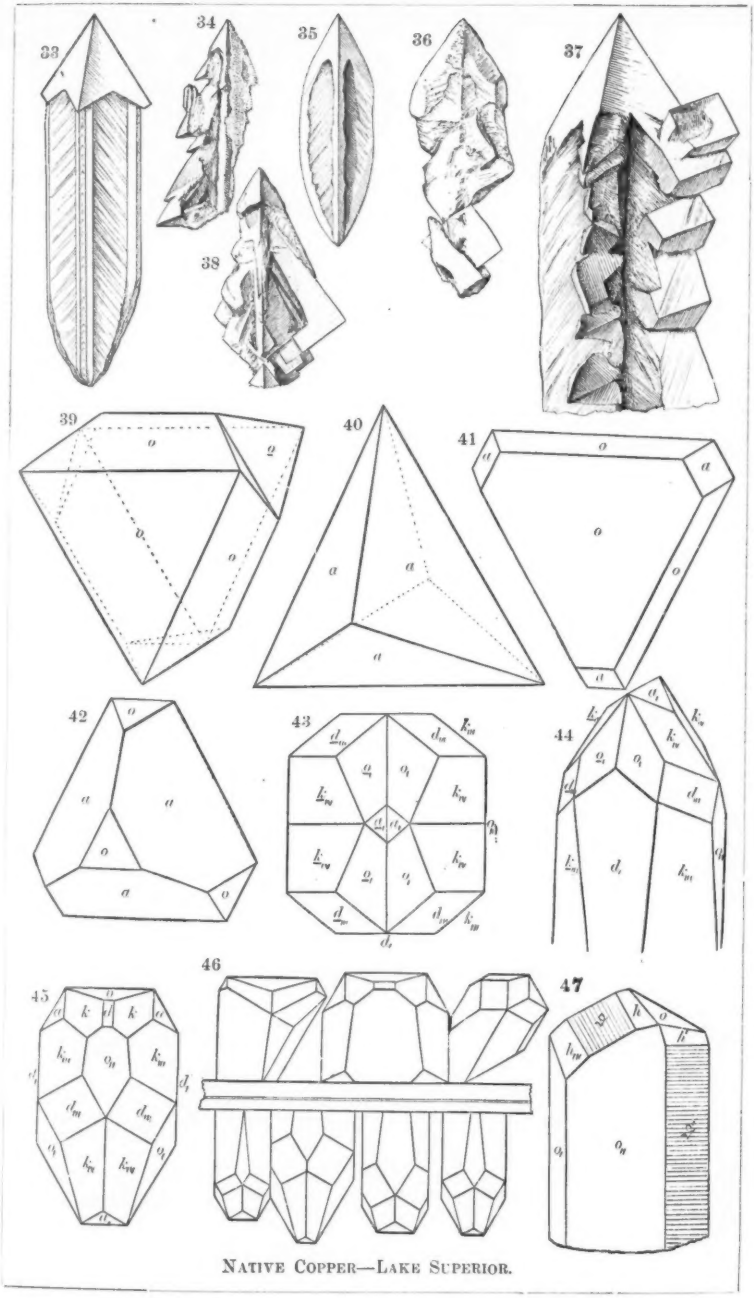

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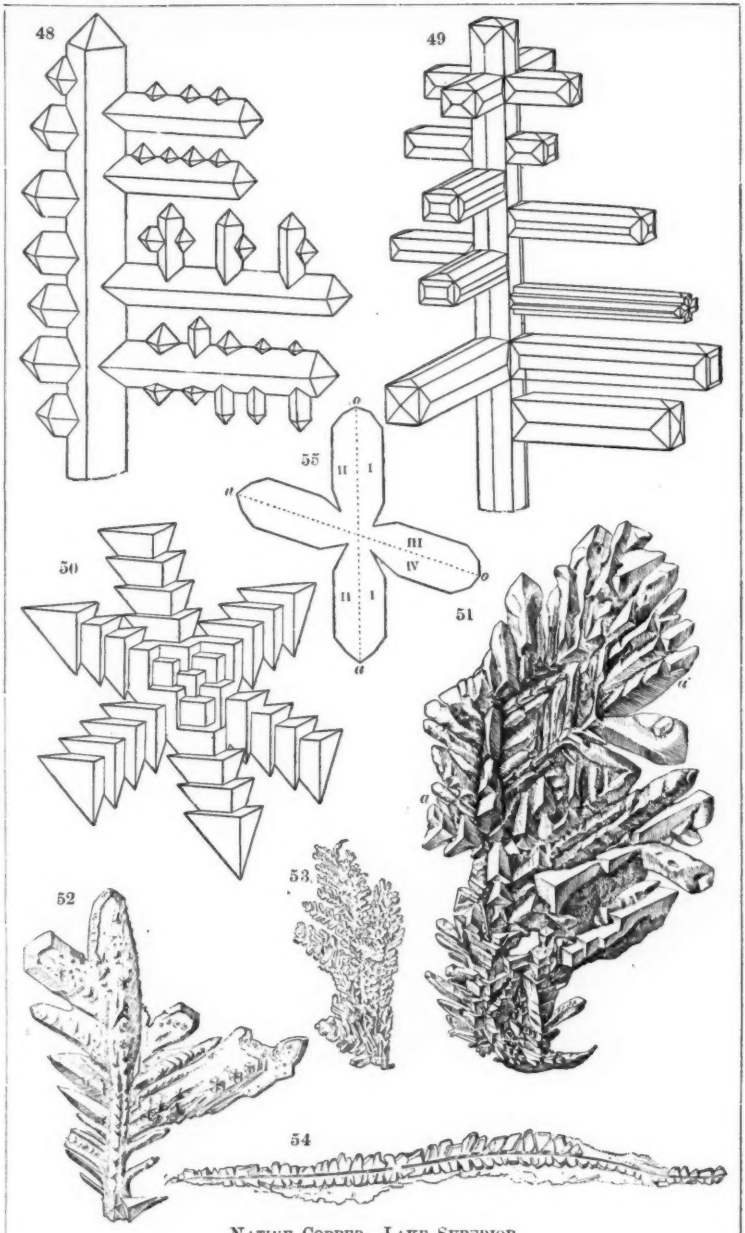

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A novel and interesting method of grouping, different from those described, is represented by several fine specimens. The crystal individuals taking part in it have already been partially described (see figs. 43, 44, 45). The larger specimen, as shown in the drawing, fig. 54, consists essentially of a long slightly curved line, deeply grooved along the center, from which project above and below, in two directions crossing at angles of 70° 32′ and 109° 28′, a series of small (2^{mm}) partial crystals. This line of elongation is one edge of the twinning octahedral plane. The crystals above and below form the two parts of fig. 45. Those below terminating in the cubic twinning-edge have a rather constant habit as shown in fig. 46. The crystals above, however, which terminate in an octahedral twinning-edge, vary much, and have a marked tendency to develop in forms similar to those below by elongation to one side in a direction normal to the cubic edge. This is suggested by the forms in fig. 46; but other crystals are very much more elongated and incline to one side at a sharp angle. Others of these crystals are broad plates showing but few planes except at the edges.

The smaller specimens of this type show also more distinctly a second similar line about the same axis and crossing the others at the octahedral angle of 70° 32′. Fig. 55 gives a cross-section in outline, and makes clear what the relations of the two series are. The individuals I and II are in twinning position with the octahedral edge above. The individuals III and IV are also in twinning position with the adjacent octahedral plane as twinning-plane, and in such a manner that the first twinning-plane is parallel to the octahedral face of III which forms the edge of III and IV. Another specimen showed the same method of complex growth, though the component crystals were simpler, some of them being simple spinal twins like fig. 39. The lines in all these cases when naturally terminated, taper off to a rather fine point.

In concluding this paper, upon a subject which cannot by any means be regarded as exhausted, the writer would express his thanks to Mr. Clarence S. Bement for his kindness in allowing him the free use of his valuable collection for several months, and also for the substantial support which has made so liberal a degree of illustration possible.

ART. XLIX.—*On the Trap and Sandstone in the Gorge of the Farmington River at Tariffville, Conn.;* by WILLIAM NORTH RICE.

THE trap of the Connecticut Valley, as is generally known, occurs for the most part in sheets intercalated among the sandstones and associated rocks, and apparently perfectly conformable with the sedimentary rocks in their generally easterly dip. Diverse views have been maintained in regard to the history of these sheets of trap, some writers considering them contemporaneous, others considering them intrusive, and still others holding that some of the sheets are contemporaneous and others are intrusive. The last view is set forth by Prof. W. M. Davis, in his paper "On the Relations of the Triassic Traps and Sandstones of the Eastern United States,"* a paper which, in addition to most important original observations bearing upon the question, gives a very complete résumé of the literature of the subject. If it be true, as I believe it is, that some of the sheets are contemporaneous and others intrusive, there is obviously need of special study to make out the history of each one. My purpose in the present note is to offer a contribution to this study by calling attention to one remarkably instructive locality.

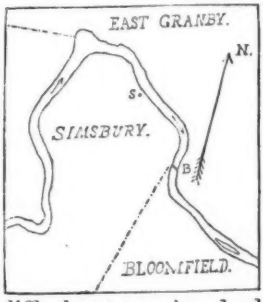
The long range of trap hills which extends almost continuously from the Hanging Hills of Meriden to Mt. Holyoke, includes (at least for the greater part of its course in Connecticut) two sheets of trap, which are generally strongly contrasted with each other.† The lower, or western, sheet is generally highly amygdaloidal, containing chlorite, calcite, datolite, prehnite, and occasionally copper ores; and does not usually show any very distinct columnar structure. The upper, or eastern, sheet is generally not amygdaloidal, and is generally much more distinctly columnar than the former. The main crest of the range is formed by the upper, or eastern, sheet of trap. The lower, or western, sheet forms sometimes a lower parallel ridge ("anterior range" of Percival). In other places the lower sheet forms merely a terrace on the western face of the main ridge. This terrace is very well marked on Talcott mountain, a portion of the range lying west of Hartford, and much visited on account of its magnificent prospect.

At the village of Tariffville, in the northeast corner of the town of Simsbury, the Farmington river cuts through the

* Bulletin of the Museum of Comparative Zoology, vol. vii (Geological Series, vol. i), no. ix.

† Percival, Geology of Connecticut, pp. 369, 390.

range of trap hills, forming a most picturesque gorge, and beautifully exposing the geological structure. The accompanying map (on a scale of $\frac{5}{6}$ths of an inch to the mile) shows the position of the localities referred to. The letter S indicates the location of the Tariffville station of the Hartford and Connecticut Western R. R. At the point marked B, where the boundary between the towns of Simsbury and Bloomfield meets the river, the river is crossed by a bridge. Southward the boundary between Simsbury and Bloomfield runs along the crest of the trap range. On the left bank of the river, for some distance above the bridge, rises a bold line of cliff about two hundred and fifty feet in height, formed by the upper sheet of trap, which here presents its usual characters, being highly columnar and not amygdaloidal. Above the bridge, the sandstone appears at the base of the cliff, forming for a considerable distance the immediate bank of the river; but, in the slight westerly bend in the immediate vicinity of the bridge, the river has cut down through the sandstone into the underlying amygdaloid. Starting accordingly, from the bridge on the left bank of the river, it is easy to examine the whole thickness of the strata from the top of the lower (amygdaloidal) trap to the base of the upper (columnar) trap. The thickness of the strata is apparently about twenty feet, though it would require a little surveying to determine the thickness with any degree of accuracy, as coverings of talus and vegetation and the water of the river prevent the whole thickness from being accessible at any one point. The rocks are more conveniently studied above the bridge than below it, being less covered by vegetation.



Starting from the margin of the stream at the bridge, and proceeding upward until we reach the upper sheet of trap, we may observe the following succession in the phenomena presented by the rocks:

1. The greenish gray amygdaloid which forms the main part of the lower sheet of trap.

2. The same becoming less lustrous, less greenish in color, and having the amygdules more copiously distributed, as we approach its upper surface.

3. A conglomerate, containing pebbles of amygdaloid. Many of the pebbles show the rounded form of water-worn pebbles. Some of them show superficial alteration, such as is common in pebbles of trap exposed to the action of air and water. The matrix in which the trap pebbles are imbedded, is the or-

dinary material of the brownish red sandstones, showing no sign of induration or alteration.

4. A red, shaly sandstone, perfectly normal and unaltered.

5. Sandstone, brighter red in color, somewhat indurated (but no more so than is frequently the case in places remote from igneous action), so fine grained as to approach in that respect the character of a shale, but not laminated, appearing vesicular where it has been weathered, but having the cavities below the surface filled with calcite.

6. Fine-grained purplish gray or dove-colored sandstone.

7. A highly metamorphosed sandstone, greenish gray in color, and so highly crystalline that hand specimens of it would be mistaken for trap. This extreme condition of metamorphism extends downward two or three feet from the junction with the overlying trap. Calcite in minute particles is disseminated through the mass of this metamorphosed rock.

8. Just at the junction of the sandstone with the overlying trap, a seam about three inches in thickness, decomposed and crumbling, appearing when wet about like a layer of mud.

9. The overlying trap, for a short distance above the junction, black and almost lusterless.

10. The black, lustrous, highly crystalline trap of the upper sheet, in its normal character.

These phenomena seem to lead irresistibly to the conclusion that the lower sheet of trap is contemporaneous. The increasingly amygdaloidal character of the trap near its upper surface, the weathered and water-worn pebbles of trap in the lowest layer of the stratified rocks, the perfectly unaltered character of the lower layers of sandstone, so strongly contrasted with the intense metamorphism of the layers near the contact with the overlying trap—all find their explanation in this view.

If the lower sheet of trap is contemporaneous, it would be a natural conjecture that the upper one is also contemporaneous. On this point, however, I have no positive evidence. I followed the bank of the river down stream till I reached the outcrop of the overlying sandstone, but found no contact visible. The only fact noted which has any significance in relation to the question, is that the trap of the upper sheet changes its character near its upper surface, becoming greenish gray in color and minutely amygdaloidal. Amygdules of calcite about the size of the head of a pin are somewhat abundant. This fact, so far as it goes, is in favor of the conjecture above stated.

The railroad to Hartford runs along the right bank of the river; and, in following the curves of the river, it passes through two cuttings in the lower or amygdaloidal sheet of trap. In the more northerly of the two cuttings is to be seen a peculiar breccia, forming a nearly vertical band two or three

feet in width, appearing almost like a vein or dike intersecting the trap. In this breccia the trap and sandstone are confusedly mixed together. The appearance is suggestive of a friction breccia;* but, on closer examination, the structure is seen to be quite different from von Cotta's description of a friction breccia. Here the matrix seems to consist of the material of the red sandstone, while the included pebbles are of trap. The trap fragments, especially the smaller ones, are extensively altered to chlorite. In the immediate vicinity of this breccia, the trap shows joints with slickensides. It would seem as if the formation of this breccia was due to some disturbance subsequent to the outflow and consolidation of the trap. The breccia may probably be considered to be a "fault-rock."† The occurrence of disturbances subsequent to the consolidation of the trap is confirmed by an examination of the more southerly cutting, where two unmistakable faults may be seen. In the southern cutting the contact of the amygdaloid with the overlying sandstone is exposed; but the rocks at that point are too much decomposed to afford any satisfactory observations. There seems to be nothing in the phenomena observed in the cuttings on the right bank of the river, which contradicts the evidence of the contemporaneous origin of the trap afforded by the section on the left bank.

Wesleyan University, Middletown, Conn., Aug. 13, 1886.

ART. L.—*Comparative Studies upon the Glaciation of North America, Great Britain, and Ireland;* by Professor H. CARVILL LEWIS. (Abstract by the author of a paper read at the Birmingham meeting of the British Association, September, 1886.)

THE object of this paper was to show that the glacial deposits of Great Britain and Ireland, like those of America, may be interpreted most satisfactorily by considering them with reference to a series of great *terminal moraines*, which both define confluent lobes of ice, and often mark the line separating the glaciated from the non-glaciated areas.

The paper began with a sketch of recent investigations upon the glaciation of North America, with special reference to the significance of the terminal moraines discovered within the last few years. The principal characters of these moraines were given, and a map was exhibited showing the extent of the glaciated area of North America, the course of the interlobate and

* Von Cotta, Rocks Classified and Described, p. 305.
† Geikie, Text-book of Geology, 2d edition, p. 161.

terminal moraines and the direction of striation and glacial movement. It was shown that, apart from the great ice sheet of Northeastern America, an immense lobe of ice descended from Alaska to Vancouver's Island on the western side of the Rocky Mountains and that from various separate centers in the Cascade, Sierra Nevada, and Rocky Mountains there radiated smaller local glaciers.

The mountains encircling the depression of Hudson Bay seemed to be the principal source of the glaciers which became confluent to form the great ice sheet. In its advance this ice sheet probably met and amalgamated with a number of already existing local glacial systems, and it was suggested that there was no necessity for assuming either an extraordinary thickness of ice at the Pole, or great and unequal elevations and depressions of land.

Detailed studies made by the author in Ireland, in 1885, had shown remarkably similar glacial phenomena. The large ice sheet which covered the greater part of Ireland was composed of confluent glaciers, while distinct and local glacial systems occurred in the non-glaciated area. The principal ice sheet resembled that of America in having for its center a great inland depression surrounded by a rim of mountains. These appear to have given rise to the first glaciers, which after uniting, poured outward in all directions. Great lobes of this ice sheet flowed westward out of the Shannon, and out of Galway, Clew, Sligo, and Donegal Bays, northward out of Loughs Swilly and Foyle, and southeasward out of Dundalk and Dublin Bays; while to the south the ice sheet abutted against the Mullaghareirk, Galty, and Wicklow mountains, or died out in the plains. Whether it stopped among the mountains or in the lowlands, its edge was approximately outlined by usual accumulations of drift and bowlders, representing the terminal moraines. As in America, this outer moraine was least distinct in the lowlands, and was often bordered by an outer "fringe" of drift several miles in width.

South of an east and west line extending from Tralee to Dungarven is a non-glaciated zone free from drift. Several local systems of glaciers occur in the south of Ireland, of which by far the most important is that radiating from the Killarney mountains, covering an area of over 2000 square miles, and entitled to be called a local ice sheet. Great glaciers from this Killarney ice sheet flowed out of the fiord-like parallel bays which indent the southwestern coast of Ireland. At the same time the Dingle mountains, the Knockmeal Down and Comeragh mountains, and those of Wexford and Wicklow furnished small separate glaciers, each sharply defined by its own moraine.

No evidence of any great marine submergence was discovered, although the author had explored the greater part of Ireland, and the eskers were held to be phenomena due to the melting of the ice and the circulation of subglacial waters. The Irish ice sheet seemed to have been joined at its northwestern corner by ice coming from Scotland across the North Channel. All the evidence collected indicates that a mass of Scotch ice, reinforced by that of Ireland and England, filled the Irish Sea, overriding the Isle of Man and Anglesey, and extending at least as far south as Bray Head, south of Dublin. A map of the glaciation of Ireland was exhibited in which the observations of the Irish geologists and of the author were combined, and in which were shown the central sheet, the five local glacial systems, all the known striæ, and the probable lines of movement as indicated by moraines, striæ and the transport of erratics.

The glaciation of Wales was then considered. Wales was shown to have supported three distinct and disconnected local systems of glaciers, while at the same time its extreme northern border was touched by the great ice sheet of the Irish Sea. The most extensive local glaciers were those radiating from the Snowdon and Arenig region, while another set of glaciers radiated from the Plinlimmon district and the mountains of Cardiganshire, and a third system originated among the Brenockshire Beacons. The glaciers from each of these centers transported purely local bowlders and formed well-defined terminal moraines. The northern ice lobe, bearing granite bowlders from Scotland and shells and flints from the bed of the Irish Sea, invaded the northern coast, but did not mingle with the Welsh glaciers. It smothered Anglesey and part of Carnarvonshire on one side, and part of Flintshire on the other, and heaped up a terminal moraine on the outer flanks of the north Welsh mountians. This great moraine, filled with far-traveled northern erratics, is heaped up in hummocks and irregular ridges and is in many places as characteristically developed as anywhere in America. It has none of the characters of a sea-beach, although often containing broken shells brought from the Irish Sea. It may be followed from the extreme end of the Lleyn Peninsula (where it is full of Scotch granite erratics), in a northeasterly direction through Carnarvonshire past Moel Tryfan and along the foot of the mountains east of Menai Strait to Bangor, where it goes out to sea, re-appearing farther east at Conway and Colwyn. It turns southeastward in Denbighshire, going past St. Asaph and Halkin Mountain. In Flintshire it turns southward and is magnificently developed on the eastern side of the mountains, at an elevation of over 1000 feet between Minera and Llangollen, southwest of which place it enters Eng-

land. There is evidence that where the ice sheet abutted against Wales, it was about 1350 feet in thickness. This is analogous to the thickness of the ice sheet in Pennsylvania, where the author had previously shown that it was about 1000 feet thick at its extreme edge and 2000 feet thick at points some eight miles back from its edge. The transport of erratics coincides with the direction of striæ in Wales as elsewhere, and is at right angles to a terminal moraine.

The complicated phenomena of the glaciation of England, the subject of a voluminous literature and discordant views, had been of high interest to the author, and had led him to redouble his efforts toward its solution. He had found that it was possible to accurately map the glaciated areas, to separate the deposits made by land ice from those due to icebergs or to torrential rivers, and to trace out a series of terminal moraines both at the edge of the ice sheet, and at the edge of its confluent lobes. Perhaps the finest exhibition of a terminal moraine in England is in the vicinity of Ellesmere and Shropshire. A great mass of drift several miles in width, and full of erratics from Scotland and from Wales, is here heaped up into conical hills which enclose "kettle-holes" and lakes, and have all the characters of the "kettle moraines" of Wisconsin. Like the latter, the Ellesmere moraine here divides two great lobes of ice, one coming from Scotland, the other from Wales. This moraine may be traced continuously from Ellesmere eastward through Madeley, Macclesfield, to and along the western flank of the Pennine chain, marking throughout the southern edge of the ice sheet of northern England. From Macclesfield the same moraine was traced northward past Stockport and Staley Bridge to Burnley, and thence to Skipton in Yorkshire. Northeast of Burnley it is banked against the Boulsworth Hills up to a height of 1300 feet, in the form of mounds and hummocks. South and east of this long moraine no signs of glaciation were discovered, while north and west of it there is every evidence of a continuous ice-sheet covering land and sea alike. The striæ and the transport of bowlders agree in proving a southerly and southeasterly direction of ice movement in Lancashire and Cheshire.

From Skipton northward the phenomena are more complicated. A tongue of ice surmounted the watershed near Skipton and protruded down the valley of the Aire as far as Bingley, where its terminal moraine is thrown across the valley like a great dam, reminding one of similar moraine dams in several Pennsylvania valleys. A continuous moraine was traced around Aire glacier. Another great glacier, much larger than this, descended Wensleydale and reached the plain of York. The most complex glacial movements in England occurred in the mountain region about the Nine Standards, where local glaciers

met and were overpowered by the greater ice sheet coming down from Cumberland. The ice sheet itself was here divided, one portion going southward, the other in company with local glaciers and laden with the well known bowlders of "Shap granite" being forced eastward across Stainmoor Forest into Durham and Yorkshire, finally reaching the North Sea at the mouth of the Tees. The terminal moraine runs eastward through Kirkby Ravensworth toward Whitby, keeping north of the Cleveland Hills, and all eastern England south of Whitby seems to be non-glaciated. On the other hand all England north of Stainmore Forest and the river Tees, except the very highest point, was under a sea of solid ice.

There is abundant evidence to prove that the ice lobe filling the Irish Sea was thicker toward its axis than at its edges, and at the north than at its southern terminus, and that it was reinforced by smaller tributary ice streams from both England and Ireland. It may be compared with the glacier of the Hudson river valley in New York, each having a maximum thickness of more than 3000 feet. The erosive power of the ice sheet was found to be extremely slight at its edge, but more powerful farther north, where its action was continued for a longer period. Toward its edges its function was to fill up inequalities rather than to level them down. It was held that most glacial lakes are due to an irregular dumping of drift, rather than to any scooping action, observations in England and in Switzerland coinciding with those in America to confirm this conclusion. Numerous facts on both sides of the Atlantic indicate that the upper portion of the ice sheet may move in a different direction from its lower portion. It was also shown that a glacier in its advance had the power of raising stones from the bottom to the top of the ice, a fact due to the retardation by friction of its lower layers. The author had observed the gradual upward passage of sand and stones in the Grindelwald glacier, and applied the same explanation to the broken shells and flint raised from the bed of the Irish Sea to the top of Moel Tryfan, to Macclesfield and the Dublin mountains. The occurrence of stratified deposits connected with undoubted moraines was shown to be a common phenomenon, and instances of stratified moraines in Switzerland, Italy, America and Wales were given. The stratification is due to waters derived from the melting ice, and is not proof of submergence.

It was held, notwithstanding a general opinion to the contrary, that there is no evidence in Great Britain of any marine submergence greater than about 450 feet. It was to be expected that an ice sheet advancing across a sea should deposit shell fragments in its terminal moraine.

The broad principle was enunciated that wherever in Great Britain marine shells occur in glacial deposits at high levels, it

can be proved, both by striæ and the transport of erratics, that the ice advanced on to the land from out of the sea. The shells on Three Rock Mountain, near Dublin, and in North Wales and Macclesfield, all from the Irish Sea; the shells in Cumberland transported from Solway Firth; those on the coast of Northumberland brought out of the North Sea; those of Airdree in Scotland, carried eastward from the bottom of the Clyde: and those from Caithness from Moray Firth were among examples adduced in proof of this principle. The improbability of a great submergence not leaving corresponding deposits in other parts of England was dwelt upon.

It was also held that there was insufficient evidence of more than one advance in the ice sheet, although halts occurred in its retreat. The idea of successive elevations and submergences with advances and retreats of the ice was disputed, and the author held that much of the supposed interglacial drift was due to subglacial water from the melting ice.

The last portion of the paper discussed the distribution of bowlders, gravels and clays, south of the glacial area. Much the greater part of England was believed to have been uncovered by land ice. The drift deposits in this area were shown to be the result in part of great fresh-water streams issuing from the melting ice sheet, and in part, of marine currents bearing icebergs during a submergence of some 450 feet. The supposed glacial drift about Birmingham, and the concentration of bowlders at Wolverhampton were regarded as due to the former agent, while the deposits at Cromer and the distribution of Lincolnshire chalk across southern England were due to the latter. The supposed esker at Hunstonton was held to be simply a sea-beach, and the London drift deposits to be of aqueous origin. Thus the rival theories of floating icebergs and of land glaciers were both true, the one for middle and southern England, the other for Scotland, Wales, and the north of England; and the line of demarcation was fixed by great terminal moraines.

The paper closed with an acknowledgment of indebtedness to the many geologists in England and Ireland who had rendered most generous assistance during the above investigation.

ART. LI.—*On certain fossiliferous Limestones of Columbia Co., N. Y., and their relation to the Hudson River Shales and the Taconic System;* by I. P. BISHOP.

THE age of the Taconic formation is a subject of so great geological interest that I need no other apology for the presentation of this paper on new discoveries of fossils in a metamor-

phic limestone on the western border of the Taconic slates in Columbia Co., N. Y., although my investigations are not yet completed.

The limestone is in the town of Chatham, just west of Canaan, and in that of Ghent, the town next south. It has along its eastern side the hydromica schist of the western Taconic belt of Emmons, the same that adjoins the Canaan fossiliferous limestone on its west side,* and the interval of slate between the two limestones is only six miles.

The limestone, or rather its eastern belt, outcrops at intervals from Chatham village on the southern border of the town, in a north-northeasterly direction, to the northeast corner of the town, and also south-southwesterly to Pulver's station, in the town of Ghent, following throughout nearly the course of the New York, Rutland & Montreal railroad.

A small exposure occurs at Chatham village in the bed of the Steine Kill, just below the trestle of the New York, Rutland and Montreal R. R.; again, two miles farther north at the railroad crossing, and thence along the track as far as "Black Rock Cut;" from there it lies to the east of the track at an average distance of a third of a mile, until near Rayville, when it crosses to the west and continues on that side nearly to Brainard's Station. South of Chatham it lies on both sides of the Hudson and Chatham R. R. as far as Pulver's Station. I have not had the opportunity to follow out its extension farther in either direction, but have no doubt that it can be traced much beyond these limits.

On the east side this limestone lies directly against the hydromica schist, and has the same northeasterly strike and southeasterly dip as the latter. The width of its exposure varies from a few feet to nearly a mile.

From Ghent northward, for about six miles, the limestone is bounded on the west by a belt of black, green, and red shales, having the same dip and strike. These shales contain fucoids and numerous graptolites, of species found in the Hudson River shales, together with two or more new species of brachiopods of the genus *Lingulops*. Parallel to this, and still farther west, lies a coarse gray sandstone of the upper part of the Hudson. This sandstone extends from Chatham village nearly to North Chatham. It is a mile wide at the former place and tapers to a thin strip south of the latter. Shales surround this on all sides.

Six miles to the west of Chatham there is another limestone belt with the same lithological characteristics, but having a general northwesterly strike. It extends from Ghent to Kinderhook Lake, where it appears to blend with the western belt,

* This Journal, xxxi, 1886, pp. 241 and 248.

no shale intervening, as far as I have been able to find. The western arm is wrinkled into parallel anticlinals and synclinals. On the western side of the arm, two narrow belts of shale, having the lithological character of the graptolitic shales, are enclosed between these parallel ridges of limestone. Over the region from Ghent westward the axes of the folds dip to the north at an angle of 45° or 50°. At Kinderhook Lake there was some evidence of a southward dipping fold. The width of the western arm of limestone ranges from three-fourths of a mile to more than two miles.

Limestone outcrops also at Rider's Mills and near Malden in the northern part of the country. I have not yet had time to trace the western arm farther north than Kinderhook Lake, and therefore do not know to which belt the latter outcrop should be assigned.

The color of the limestone of both arms is bluish gray or dove-colored. It contains veins of calcareous spar which cross the surface irregularly, giving it a checkered appearance. It varies from massive thick-bedded limestone to calcareous shale. In all localities where I have observed it, there are brecciated layers present, made up of lenticular fragments of limestone, pieces of shale, and siliceous material. These usually contain limonite concretions, evidently changed from pyrites by oxidation and having nuclei of organic matter. Interspersed with the limestone are siliceous layers, both massive and thin-bedded, some of which are nearly pure sandstone or quartzite while others are calcareous. These do not resemble the Hudson River sandstones mentioned above in color, texture or appearance, and are undoubtedly distinct from them. It will be noticed that the series is similar to that described by Mather* at Great Neutin Hook, and probably belongs to the same system.

The fossiliferous localities are three in number and all are in the eastern belt. From the first, situated about midway between Chatham and Ghent, only crinoid stems have been taken. The second is situated at the crossing of the N. Y. & M. R. R., two miles north of Chatham; and the third a mile still farther north, on the farm of Mr. Joel Angell; and these two have furnished the fossils mentioned below. They were first noticed by me about April 1, 1886, at the R. R. crossing, and at the upper locality a few weeks later. Some layers of the rock are made up almost entirely of organic remains in which gasteropods predominate. There are, also, crinoid stems in abundance. Among the brachiopods there are several well-marked valves of *Leptæna sericea* and *Strophomena alternata*. The external markings of the gasteropods are so effaced by metamorphism and weathering that it is very difficult to distinguish species.

* Geology of N. Y., Pt. IV, 1843.

There are, however, several specimens of a slender *Murchisonia* which is probably *M. gracilis*, a single doubtful *Maclurea* and specimens of *Ophileta* in abundance. I have found one incomplete *Orthoceras*, but in too poor condition to be identified. Near the R. R. crossing, I obtained also a well-preserved bryozoan, a new species of the genus *Ptilodycta*.

While the two species of brachiopods which have been positively identified belong to both the Trenton and the Hudson River periods, the fact that the rocks of the latter do not include limestones in eastern New York, is strong evidence that these fossils are of Trenton age. The character of the associated genera and the appearance of the rock also strengthen this view.

If the limestones of the eastern and western belts are identical, as seems to be proved both by their connection at Ghent and by their similar lithological character, there can be no reasonable doubt that the limestone containing Trenton fossils immediately underlies the graptolitic shales of the Hudson River group.

The facts, as far as collected, are suggestive of a synclinal having the Trenton limestone outcropping on both sides, and with the eastern edge pushed over westward.

During the coming year I hope by mapping out the district carefully, and noting the strikes and dips, to get more exact information than I am able to present to-day.

Before closing I wish to express my indebtedness to Professor James Hall, the State Geologist and his assistants, who have identified for me the fossils found, and without whose aid this paper would not have been written.

LII.—*Crystallized Vanadinite from Arizona and New Mexico;* by S. L. PENFIELD.

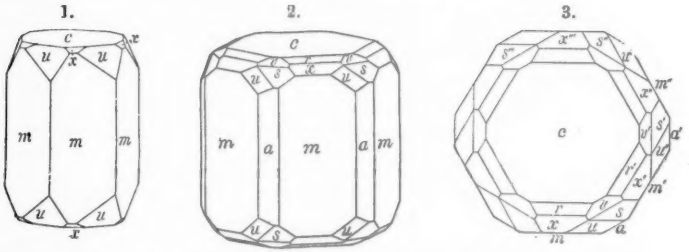
THE occurrence of vanadinite in various localities in Arizona has been noticed by B. Silliman* and W. P. Blake,† and of crystals from the Black Prince Mine, Pinal Co., Arizona, by F. H. Blake.‡ The latter mentions, as the most common forms, prism and pyramids of the first order, prism of the second order and the basal plane. Through the kindness of Mr. L. Stadtmüller I have been able to examine a number of specimens from the above and other localities in Arizona and New Mexico which were in the collection of the late Professor B. Silliman. I have also examined a number of specimens in the collection of Professor Geo. J. Brush. The crystals from Pinal

* This Journal, III, xxii, 198.
† This Journal, III, xxii, 410.
‡ This Journal, III, xxviii, 145.

Co., Arizona, merit especial attention; they are small, seldom over 1^{mm} in length, of a deep red color, and usually show the very simple combinations mentioned by Mr. Blake. A few highly modified crystals were found possessing pyramidal hemihedral forms which are of interest because these forms have rarely been observed in this species and show the close relation in habit between crystals of this mineral and apatite. They possess highly polished faces and are well suited for measurement. I have been able to identify the following forms:

m, $10\bar{1}0$, I	x, $10\bar{1}1$, 1
a, $11\bar{2}0$, i-2	y, $20\bar{2}1$, 2
h, $\pi\, 21\bar{3}0$, $\frac{1}{2}(i\text{-}\frac{3}{2})$	v, $11\bar{2}2$, 1-2
c, 0001, O	s, $11\bar{2}1$, 2-2
r, $10\bar{1}2$, $\frac{1}{2}$	u, $\pi\, 21\bar{3}1$, $\frac{1}{2}(3\text{-}\frac{3}{2})$

The hemihedral forms h and u have previously been observed, the former by C. Vrba* on crystals from Kappel, Carinthia, the latter by M. Websky† on crystals from Cordoba, Argentine Republic. Crystals from Pinal Co. showing these combinations are not uncommon. The most common combination is shown in fig. 1. The pyramid u can frequently be seen on both ends of the crystals, or where the free end shows, can be traced all around the crystals. Of pyramids of the first order x is the most common, but r or y, sometimes both, are frequently associated with it. Of pyramids of the second order s occurs



frequently, v is seldom met with. Fig. 2 shows the occurrence of these planes which was observed on a single crystal; fig. 3 is a basal projection of the same. The hemihedral prism h is not common, but I have observed it on a number of crystals; on one attached by its side I was able to measure it three times on the edges which were available; it was in combination with m, a and c only. From the best measurement, $a \wedge s\,(11\bar{2}0 \wedge 11\bar{2}1) = 35°\ 6\frac{1}{2}'$, the axial ratio $a : c = 1 : 0{\cdot}71121$ is obtained. This agrees closely with the ratio given by Schabus,‡ $1 : 0{\cdot}71157$,

* Zeitschr. Kryst., iv, 353. † Zeitschr. Kryst., v, 542. ‡ Pogg. Ann., c, 297.

and quite closely with that of Vrba,* 1 : 0·7112177. The measured angles are as follows :

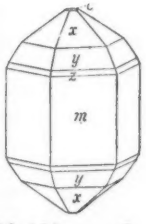
	Measured.	Calculated. Vrba.	Calculated. Author.
$a \wedge v\ 11\bar{2}0 \wedge 11\bar{2}2$	= 54° 30′	54° 33′	54° 35′
$m \wedge r\ 10\bar{1}0 \wedge 10\bar{1}2$	= 67° 42′	67° 39′	67° 41′
$m \wedge x\ 10\bar{1}0 \wedge 10\bar{1}1$	= 50° 33′	50° 34′	50° 36′
$m \wedge y\ 10\bar{1}0 \wedge 20\bar{2}1$	= 31° 20′	31° 18′	31° 20′
$x \wedge x\ 10\bar{1}1 \wedge 01\bar{1}1$	= 37° 2′	37° 2′	37° 0′
$x \wedge s\ 10\bar{1}1 \wedge 11\bar{2}1$	= 26° 36′	26° 38′	26° 36′
$s \wedge u\ 11\bar{2}1 \wedge 21\bar{3}1$	= 14° 0′	14° 2′	14° 1′
$m \wedge u\ 10\bar{1}0 \wedge 21\bar{3}1$	= 30° 55′	30° 50′	30° 52′
$c \wedge u\ 0001 \wedge 21\bar{3}1$	= 65° 17′	65° 19′	65° 17′
$m \wedge h\ 10\bar{1}0 \wedge 21\bar{3}0$	= 19° 9′	19° 6′	19° 6′

It will be seen that the angles agree closely with those calculated from the axial ratio of Vrba, also closely with those of the author.

The crystals contain only a trace of As_2O_5, which was proved by testing in the Marsh apparatus.

I have also examined crystals from the Sierra Grand Mine, Lake Valley, Grant Co., New Mexico. These are straw yellow in color and have the habit shown in fig. 4, many of them have a more prominent basal plane. The prism m is usually striated horizontally. The crystals react strongly for V_2O_5 and in the Marsh apparatus for As_2O_5, corresponding exactly to the description given by F. A. Genth and G. vom Rath† to the species named by them Endlichite (vanadium mimetite). The observed forms are given in fig. 4, $z = 30\bar{3}1$, 3. The crystals do not admit of very accurate measurement. From the best measurement $x \wedge x'$ $(10\bar{1}1 \wedge 01\bar{1}1) = 38°\ 12'$ we obtain the ratio $a : c = 1 : 0{\cdot}7495$. Other measured angles are :

4.



	Calculated. Endlichite.	Calculated. Vanadinite, Author.
$x \wedge x'''\ 10\bar{1}1 \wedge \bar{1}011$ = 82° 3′	81° 45′	78° 47′
$y \wedge y'\ 20\bar{2}1 \wedge 02\bar{2}1$ = 51° 51′	51° 18′	50° 34′
$x \wedge y\ 10\bar{1}1 \wedge 20\bar{2}1$ = 18° 25′	19° 7′	19° 16′
$x \wedge z\ 10\bar{1}1 \wedge 30\bar{3}1$ = 27° 44′	28° 3′	28° 31′

It will be seen from the above that the angles do not agree well with the calculated angles of vanadinite. The presence of As_2O_5 in the mineral must therefore tend to very perceptibly increase the length of the vertical axis.

Mineralogical Laboratory, Sheffield Scientific School, June 16, 1886.

* Loc. cit.

† Proc. Amer. Phil. Society, xxii, 367.

Art. LIII.—*The Viscosity of Steel and its Relations to Temper;* by C. Barus and V. Strouhal.

Introductory.

In an earlier number of the Journal, we expressed the belief that the qualities of retaining magnetism exhibited by steel would probably stand in relation to the viscous properties of the metal. In the present paper we make a first search for such a relation. The work is restricted to torsional viscosity because it usually exists in larger amount, and is much more accurately measurable than any of the other manifestations of viscosity. Possibly it may be brought more rationally into comparisons with magnetic phenomena. We therefore develop partially (i. e. so far as is necessary for our especial purposes) a new and very sensitive differential method for the study of torsional viscosity. Having applied it to steel, we compare the results obtained with the known behavior of permanent linear magnets, tempered under like conditions. During the course of the experiments we incidentally come upon certain ulterior results (viscosity of iron, glass).

In our magnetic comparisons we have endeavored to avoid prematurity. Many inferences of the original draught have been cropped. We do not wish to ignore the magnetic effect of the chemical changes of steel. We have merely endeavored to *circumscribe* the magnetic effect of carburation, by exploring the magnetic importance of certain mechanical properties of steel. To do this we have studied, abstractly as it were, the occurrence of permanent magnetism in a medium of continuously varying viscosity, without insisting on an inherent relation between retentiveness and viscosity.

Literary notes.—The necessary existence of viscosity in solids was pointed out, discovered, and its nature described by Weber;* but it is to Kohlrausch's† extensive researches that we owe the

* Weber: Götting. Gelehrt. Anz., St. viii, 1835; Pogg. Ann., xxiv, p. 247, 1835; ibid., liv, p. 1, 1841; Comm. Soc. Götting., iii, p 45, 1841. Weber's researches express the amount of viscous deformation in terms of time by a hyperbolic formula with three coustants.

† Kohlrausch: Pogg. Ann., cxix, p. 337, 1863; ibid., cxxviii, pp. 207, 399, 1866; ibid., clv, p. 579, 1875; ibid., clviii, p. 337, 1876. The author subjected fibers of a great number of substances to torsional, tensile and flexural stress, and discusses the amount of deformation in each case in its dependence on time and on temperature. The results are too elaborate to be excerpted here. The author finds it necessary to use exponential relations with three and even four constants to describe the results completely. In this place we advert, moreover, to the papers of Neesen (Pog. Ann., cliii, p. 498, 1874; ibid., clvii, p. 579, 1876; Wied. Ann., vii, 460, 1879), of Braun (Pogg. Ann., cxix, p. 337, 1876), of Wiedemann (Wied. Ann., vi, p. 496, 1879) which supply important details of critical discussion. Perhaps we may even add Pernet's well-known thermometric researches (Carl's Rep., xi, p. 257, 1875, and elsewhere).

bulk of our knowledge of to-day. A new method of research was indicated by Sir William Thomson,* which method was developed, independently of Thomson we believe, by Streintz † and by Schmidt.‡ Thomson § concisely defined the terms now in English use.

Plan of research.—We purposed at first to study the viscosity of steel from two distinct stand-points: one part of our work was to consider viscosity in its relations to temperature; the other part, viscosity in its relations to hardness. Indeed we have as yet no data of this kind for steel, at all. For other substances Kohlrausch‖ and after him Streintz¶ and Pisati** had already studied viscosity and temperature with some detail though in a direction differing somewhat from our own. Very recently, however, Schroeder†† of Freiburg has experimented in a line of research quite identical with the one upon which we had determined; and though his data do not include steel, the results obtained for other metals are sufficiently pronounced to make a special investigation of steel superfluous, at least so far as regards its *present* bearing on our work. Schroeder‡‡ finds "Der bei 100° begonnene Verlauf der Nachwirkung wird durch abkühlung des Drahtes auf Zimmertemperatur unterbrochen; nach erneuter Erwärmung auf 100° wird die vorher unterbrochene Drehung fortgesetzt." We pointed out§§ that in case of drawn metals, of quenched glass (Rupert's drops) and we inferred also in case of tempered steel, energy has been stored up in virtue of the rigidity of the material; and that on exposure to temperature (annealing), the available excess of stress is made to produce the observed viscous deformation precisely in the way in which Schroeder has found it for applied torsional stress.

*Sir William Thomson: Phil. Mag. (IV), xxx, p. 63, 1865. Thomson refers the loss of energy of vibration to the existence of molecular friction.

† Streintz: Pogg. Ann., cliii, p. 387, 1874; Wien. Ber., lxix, part 2d, p. 355, 1874. Using a vibration method the author discusses elaborately the effect of viscosity on the logarithmic decrement.

‡ Schmidt: Wied. Ann., ii, pp. 48, 241, 1877, supplements Thomson's and Streintz's results, and is able to express logarithmic decrement in terms of time by Weber's formula of three constants. We may add Cohn (Wied. Ann., vi, p. 403, 1879), Hopkinson (Phil. Trans. 1877), Warburg (Wied. Ann., xiii, p. 141, 1881), Auerbach (Wied. Ann., xiv, p. 308, 1881), Kohlrausch (Pogg. Ann., cxxviii, 1886), Ewing (Phil. Trans., p. 545, 1885) and others who discuss viscosity as manifesting itself in phenomena of conductivity (Cohn), residual static charge (Hopkinson, Kohlrausch), magnetism (Auerbach, Warburg, Ewing and others).

§ Thomson: l. c.

‖ Kohlrausch: Pogg. Ann., cxxviii, p. 216, 1866; ibid. clviii, p. 371, 1876.

¶ Streintz; Wien. Ber. lxix, p. 337, 1874; also Schmidt, l. c.

** Pisati: Wien. Ber., lxxx, p. 427, 1879. Also Gaz. Chim. Ital., 1876, 1877.

†† Schroeder: Wied. Ann., xxviii, p. 369, 1876. ‡‡ Schroeder: l. c., p. 388.

§§ Bull. U. S. G. S., No. 14, p. 196, 1885; this Journal, xxxi, p. 452, 1866.

Method of Experimentation.

Apparatus.—1. For the reasons given the scope of this paper has been limited to a study of the viscosity of steel, in its relations to temper. We endeavor therefore to determine the difference of viscosity which corresponds to a given known difference of hardness. The following differential method of measurement, the principle of which can be made clear in a few words, naturally suggests itself:

Given a pair of steel wires one of which is always glass-hard, the other of known temper; let them be made the threads of a *bifilar suspension* provided with suitable means for the measurement of the angular motion of the line defined by the lower double-point of attachment, relatively to the upper line of attachment; finally let a twist of $+\phi$ be imparted to one steel wire, a twist of $-\phi$ to the other. If now the system be left to itself, and if the two wires be equally viscous the bifilar system (*cæt. par.*) will remain at rest. If on the other hand the viscosities be unequal, the lower free part of the bifilar will move around the vertical let fall from the upper part. The sign of this angular motion will be that of the twist of the wire of greater viscosity; its amount (*cæt. par.*) directly dependent on the difference of viscosity of the pair of wires under experiment. One of the forms of apparatus actually used is given in the annexed diagram, figures 1 and 2, the former on a scale of $\frac{1}{4}$. The couple of steel wires *awwg* and *axxg* to be tested, is fastened above to a massive piece of brass *ABC* and below to a similar piece *DEGF*. *ABC* is fixed firmly to the wall at some distance from it, and all incidental motion or displacement is registered by the mirror *M*, adjustable at pleasure by aid of the screw-arms *fed* and *bc*. *DEGF* is free to move under the influence of the bifilar couples and motion is similarly registered by the mirror *N* adjustable at pleasure by aid of the screw-arms *mlk* and *hi*. To keep the line of symmetry of the piece *DEGF* vertical, to deaden incidental vibrations, and to give general stability to the whole bifilar adjustment, we suspended a heavy lead disk *HQ* (5 lbs.) from the screw *r*. *HQ* is partially immersed in water contained in a glass bell-jar *ILK* also (adjustably) attached to the wall.

The steel wires are inserted and then fastened in the apparatus as follows: To keep the two steel wires (about 33^{cm} long) under a permanent strain of torsion, each is softened about 2^{cm} from the ends inward. The soft parts are then bent into a hook-like loop just large enough to slide over the screws of the little brass bolts *a* and *g*. Having fastened the lower ends by the bolt *g*, the upper ends are each twisted 180° against each other and then also fastened by the bolt *a*.

The ends of this twisted system are now to be secured to the blocks of brass *ABC* and *DEGF*. One method of fastening is given ($\frac{1}{2}$ actual size) in figure 2, the parts of which are lettered similarly to figure 1. The two wires, *w* and *x*, are pressed firmly against a little rectangular piece of steel, *o* by aid of the bolt *pp'* and the nut *qq'*. The bolt is provided with a square hole near its head, through which *o* and the steel wires may easily be passed. A little pin prevents *o* from rotating around the axis of the screw, thus diminishing liability to breakage. In the apparatus figured it is necessary to slide the bolts *pp'* over the wires *w*, *x*, before the torsion is applied by fastening *a*.

In a more convenient form of apparatus, perhaps, we replace the brass blocks *ABC* and *DEGF* by little hand vises, the axle of the lower one of which has been perforated and fitted with a screw subserving the purposes of *r* in the figure. By aid of a disc of lead vertical symmetry of the whole apparatus is here also maintained.

The advantages of this form of apparatus, apart from our own special purposes, is this, that

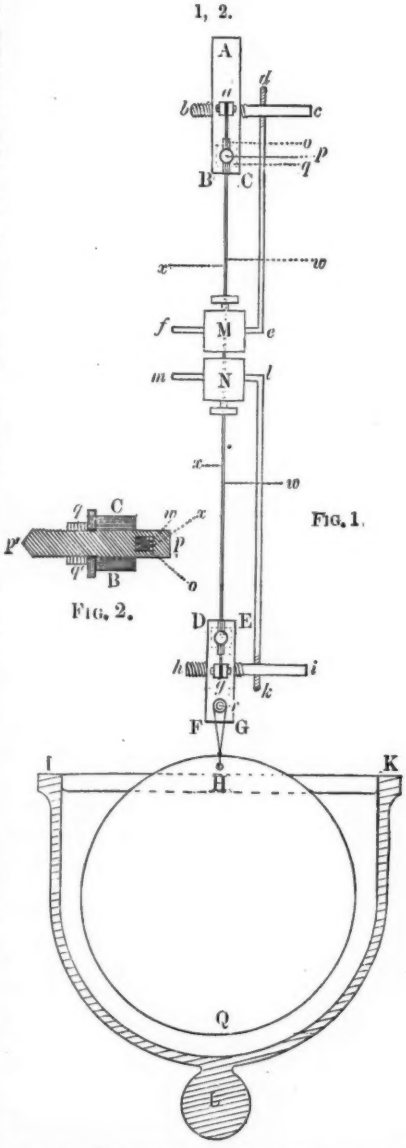


Fig. 1.

Fig. 2.

Fig. 1.—Differential apparatus for torsional viscosity (scale $\frac{1}{2}$).
Fig. 2.—Device for suspension (scale $\frac{1}{2}$).

with a single adjustment, the viscous movement can be traced with extreme accuracy for an indefinite length of time. There is no doubt that in some of the cases examined such motion will demonstrably exist even for a year after the torsion has been imparted. Kohlrausch's method is an absolute method; but his wire must be twisted and untwisted once for each observation. The method of logarithmic decrement is difficult of interpretation, is really a complex method and limited to short intervals of time.

In experimenting with glass it was necessary to modify the apparatus so that twists less than $\phi=180°$ could be applied. This is easily done by perforating the screw of the upper bolt and passing the glass fiber through the hole. Torsion in any amount may then be applied to the projecting fiber.

2. Our second (tubular) apparatus combines with the advantages of the one just sketched, the ulterior desideratum of enabling the observer to follow the viscous detorsion immediately after applying stress; and therefore also of exhibiting the effect of positive torsion immediately succeeding negative torsion and vice versa; or of studying the effect produced by an indefinite number of alternations of the sign of the twist. In the second form of apparatus the wire is introduced into a narrow tube just large enough to surround it. The tube is fixed above and fastened to the wire below. Twist is imparted to the wire and through it to the tube. The observations, in other respects, are conducted as above.

Method of Observation.—In both forms of apparatus, angles are registered by Gauss' method of telescope* and scale. We secure extreme accuracy by using two mirrors, one of which (stationary) furnishes a reliable fiducial mark for the other (movable). These mirrors are easily so adjusted that their respective scale-images appear *simultaneously* in the field of the telescope one above the other and intersected by the same cross-hair. Indeed it would not be difficult to arrange this device that the stationary image could be used as a vernier on the moving image.

Method of Tempering.—The wires used (Stubs' steel) were hardened galvanically as described elsewhere.† To Professor H. A. Rowland, who placed his dynamo-electric machine at our disposal for this purpose, and favored us with the benefit of his advice during almost the entire afternoon, we owe our very cordial thanks.

The annealing was effected by drawing the glass-hard wires through a zone of constant temperature by clockwork.‡

* Three wood screws, the head of one of which is planed, of another hollowed out conically, make a good adjustable plane-dot-slot arrangement.

† Bull. U. S. G. S., No. 14, p. 29; Wied. Ann., xi, p. 932, 1880.

‡ This Journal, xxxii, p. 279, 1886.

Elimination of Errors.—1. The steel wires to be used in these experiments are all about 0·1^{cm} in thickness. Hence to determine the condition of equilibrium or motion in the torsional apparatus described, it is necessary to consider the respective moments of the bifilar couple (M_b), of the torsional couple (M_τ) and of the flexural couple (M_f), by which the movable end is actuated.

The moment of the bifilar couple has the well-known form*

$$M_b = \tfrac{1}{4}\frac{ll'}{L} mg \sin\varphi \quad . \quad . \quad . \quad (1)$$

where l and l' are respectively the distance apart of the upper ends and the lower ends of the bifilar wires, L the vertical distance and φ the horizontal angle between the lines l and l', mg the weight of the whole suspended adjustment. To mg should be added one-half the weight of the wires.

The moment of the torsion couple is $M_\tau = \tau\varphi$, where τ is the sum of the torsional coefficients of the wires. This applies because the sum of the stored torsional moments, for $\varphi = 0$, is $\psi + (-\psi) = 0$. We may give the equation M_τ an experimentally convenient form by substituting for τ the approximate value* derived in elastics. We obtain

$$M_\tau = \frac{2\pi}{5}\frac{E\rho^4}{L}\varphi \quad . \quad . \quad . \quad (2)$$

where ρ is the radius of the steel wires used, E the C. G. S. value† of the modulus of elasticity of steel.

The moment of the flexural couple is more involved. If p be the distance apart of vertical planes passing through the bifilar wires, if f be the horizontal component of the flexural force, then the flexural couple is $M_f = fp$. We have however by geometry, $p = (ll' \sin\varphi)/s$, where s is the sum of the horizontal projections of the wires. We have moreover given us in elastics

$$E = \frac{4}{3} f \frac{L^3}{\pi\rho^4} \frac{1}{\frac{s}{2}},$$

and therefore the couple in question becomes

$$M_f = \frac{3\pi}{8}\frac{ll'\rho^4}{L^3} E \sin\varphi \quad . \quad . \quad , \quad (3)$$

The equations 1, 2 and 3 enable us to choose the dimensions of the wire and of the apparatus as well as to select conditions

* C. F. Maxwell, ii, p. 108, 1881; Kohlrausch Leitfaden, p. 167, 1884.

† Poisson's coefficient is in the following estimate taken at $\frac{1}{4}$.

‡ If E' be the current technical modulus referred to the kilogram and square millimeter, $E = E'g \times 10^5$.

of experiment such that the torsional couple may alone be effective. The following are extremely unfavorable phases of the best available values, in question:

$$l=l'<0{\cdot}2^{\text{cm}};\ L>25^{\text{cm}};\ m<2500^{\text{g}};\ \varphi<0{\cdot}2^{\circ};$$
$$\rho=0{\cdot}041^{\text{cm}};\ E=2\times10^{12}\ (ml^{-1}t^{-2}).$$

In view of the small values of φ it is sufficient to compare the coefficients only. We obtain nearly

$$M_b : M_\tau : M_f = 1000 : 280000 : 20.$$

Hence it appears that in the case of the chosen dimension the most unfavorable effect of the bifilar and flexural couples combined, is less than 0·4 per cent of the torsional couple. Moreover the torsional couple becomes more predominant as the angle of deviation, φ, increases so that no serious inaccuracy from the discrepancies here enumerated need be apprehended.

2. When we operate with glass-hard steel, we encounter so many mechanical difficulties, that the conditions postulated in the foregoing analysis can not be immediately assumed. We can not, for instance, adjust the tensions of the two wires precisely to equality. Nor is it easy so to store the permanent torsion that the parallelism of the lines joining the upper and lower points of suspension remains intact. Under these circumstances flexural and bifilar couples may have very different values from the ones accepted and the moments, as a whole, will form a complex aggregate. Although it is improbable that the flexural and bifilar discrepancies will exceed the limits of error investigated, it is none the less desirable to determine them by direct experiment. This can be done with convenience and great accuracy.

Let the water be removed from the jar *ILK* and the system put in vibration around a vertical and in such a way that the angle φ remains small. Then the circumstances of motion are given by

$$\frac{4\pi^2 K}{T^2}=\tfrac{1}{4}\frac{W}{L}mg+\tau+\frac{\delta M_f}{\delta\varphi},$$

where K is the moment of inertia of the bifilar body, T the time of a complete vibration. If we replace the steel wires by threads for which τ and $\delta M_f/\delta\varphi$ are zero, we may find the value of the bifilar coefficient in terms of the other two. We cite the following typical experiment:

Steel wires: $T_s=0{\cdot}025$ sec.; $L=26^{\text{cm}}$; $l<0{\cdot}1^{\text{cm}}$;
Brass capillary wire: $T_b=0{\cdot}35$ sec.; $L=30^{\text{cm}}$; $l=0{\cdot}2^{\text{cm}}$; $l'=0{\cdot}3^{\text{cm}}$.

If we reduce the results for capillary brass wire to the L and l which obtain for steel, we deduce T_b40 sec.$=0$· Hence the

bifilar coefficient is less than 0·4 per cent of the combined torsional and flexural coefficients, in very unfavorable values of the chosen dimensions. This experimental result agrees with the one calculated above.

3. The following static method is better, being exhaustive and final. Let the lower ends of the pair of identical steel wires, A and B, be fastened with the bolt. Let rotation at this end be temporarily checked. Then we may store like degrees of torsion by twisting the upper ends of the wires in the following three ways:

a. Let the wire A be twisted $+360°$ and then fastened to B. Left to itself the upper end of the system will rotate $-180°$ so that the residual torsion of A is $+180°$; of B is $-180°$. The total couple actuating the bifilar body then is of the form $\pm M_b + M_\tau \pm M_f$.

b. Let the wires A and B be twisted $+180°$ and $-180°$ respectively and then fastened together. Left to itself the upper end of the system will not move. The residual torsion is therefore the same as in case *a*; but the total couple here actuating the bifilar body is $M_\tau \pm 0$. This is the case premised in the analysis which introduces this paragraph.

c. Let the wire B be twisted $-360°$ and then fastened to A. Left to itself the upper end will rotate $+180°$, so that the residual torsions on A and B are the same as in cases *a* and *b*; but the total couple which in case of viscous motion actuates the bifilar body has now the form $\mp M_b + M_\tau \mp M_f$.

This is the device: We are able to *commutate*, as it were, the combined flexural and bifilar couples relative to the torsional couple of *fixed* sign. In the results below this test is frequently applied and we will there show that for the chosen dimensions the torsion couple need alone be considered.

4. In the case of the tubular apparatus the present precautions are at once superfluous. Here each wire is introduced into the tube and compared with the next wire introduced under like circumstances. The tubular apparatus is specially adapted for the investigation of viscous detorsion in its dependence on the applied torsional stress, as well as on time. But the same work may also well be done with the bifilar.

The viscous effect of the relative sections of the wires and allied observations, with a bearing on viscosity proper, can more expediently be made after the experimental data have been communicated. It is convenient to insert a few remarks on the rigidity of efficient parts of the above apparatus here. If the tubular adjustment d be the diameter of the wire, d_1 and D_1 the diameters of the tube, if L symbolize the effective length, ψ the amount of stored twist, G the rigidity, we have, in view of the equal couples,

$$\psi\frac{\pi d^4 G}{32L}=\psi_1\frac{\pi(D^4_1-d^4_1)G_1}{32L_1} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now in order to make sharp comparisons on the viscosity of solids, in order to investigate its dependence both on time and on stress, the apparatus is so to be adjusted that *like stresses produce like strains* in the substances compared. Hence put $\psi=\psi_1$, whence

$$\frac{d^4}{D^4_1-d^4_1}=\frac{G_1L}{GL_1}=\text{const.}\frac{L}{L_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This applies to the bifilar apparatus for $d_1=0$. The equation (2) shows at once how to study viscosity under conditions in which like stresses produce like strains upon like sectional areas of the viscous solids compared.

Notation.—In Bulletin 14 we used the word "retentiveness" in the restricted German sense to designate magnetic stability, or the property in virtue of which a magnet resists such influences as temperature, percussion, time. The common English use of the term is much broader than this and refers to residual induction* in a general way. Fortunately the context of our paper is sufficiently clear and does not admit of serious misapprehension. Inasmuch as measurement of total induction has not yet fallen properly within the scope of our work, we purposely withhold many obvious allusions to magnetic permeability. We moreover retain the term permanent magnetization to denote the magnetic moment *per unit of mass* of a permanently saturated rod, for the sake of uniformity with our earlier notation. Its ratio to magnetic intensity is therefore the density of steel.

To avoid troublesome circumlocution we use the adjective "viscous" with the very broad meaning of "pertaining to viscosity." Such expressions as "viscous phenomena" though not elegant are convenient. Similarly we often speak without confusion of "linear magnetization" where "magnetization of a linear rod" is meant.

Experimental Data.

Introductory explanations.—The following tables, Nos. 1 to 26, contain results for the viscosity of steel in different states of temper. To these are appended other tables of a miscellaneous kind. For convenience of comparison we insert a little index. The apparatus used in obtaining the data are designated by the Roman numerals in the first column. Nos. I to IV are

* Mr. Ewing proposes a new and very elegant extension of the current use of "retentiveness." He defines it as "resistance to any change of magnetic state which (magnets) exhibit whenever the magnetic field in which they are placed suffers any change."- *Phil. Trans.*, ii, 1885, p. 526.

different forms of the bifilar adjustment; No. V is the tubular instrument. The index also contains the numbers of the rods or fibers joined together to make the bifilar couple and other information readily understood. Glass and iron fibers are lettered. It is to be remembered that in the steel measurements one of the pair of wires is always glass-hard, the other annealed as specified.

Index to Tables.

I. Experiments proper.

Temper of the rod coupled with glass-hard.

Apparatus No.	Annealed 20°.	Annealed 100°.	Annealed 190°.
I.	Table 1, Rods 47, 48.	Table 5, Rods 3, 4. Table 5A, Rods 43, 44.	
II.	Table 2, Rods 1, 2.	Table 6, Rods 5, 6. Table 6A, Rods 45, 46.	Table 10, Rods 11, 12.
III.		Table 7, Rods 7, 8.	Table 13, Rods 13, 14. Table 13A, Rods 19, 20
IV.		Table 8, Rods 9, 10.	Table 14, Rods 15, 16.

Apparatus No.	Annealed 360°.	Annealed 450°.	Annealed 1000° (soft).
I.		Table 19, Rods 23, 24.	Table 23, Rods 27, 28 (soft).
II.	Table 16, Rods 17, 18.	Table 20, Rods 25, 26.	Table 24. Rods 29, 30 (commercial drawn).
III.			Table 25, Rods 31, 32 (commercial annealed).
IV.	Table 18, Rods 21, 22.		Table 26, Rods 33, 34 (annealed from glass-hard).

II. Miscellaneous experiments.

Apparatus No.	Glass. *a.*	Glass. *b.*	Iron drawn. *c, k.*
I.	Table 27, Rod 35.	Table 28, Rods 36, 42.	
II.			Table 29, Rod 37. Table 30A, Rod 50.
III, IV.			
V.			

Apparatus. No.	Iron soft. *g, d.*	Brass tube (thick). *e.*	Brass tube (thin). *f.*	Misc. soft steel.
I.	Table 30, Rod 38.			
II.				
III.				Table 34, Rods 51, 52.
IV.				
V.		Table 31, Rods 39, 40.	Table 32, Rod 41.	

Experiments proper.—In tables 1 to 26, R denotes the distance between mirror and scale, L the efficient length of the steel (bifilar) wires, l the distance apart of the upper and lower points of suspension. ϕ (in degrees) is the stored torsion, imparted to the whole length (30^{cm}) of wire, positively or negatively as specified, whereas φ_0 (in radians) is the amount of angular motion (differential detorsion) of the bifilar system due to viscosity per centimeter of length of the system of two steel wires. Positive values of ϕ and φ_0 refer to the same angular direction, and φ_0 is arbitrarily put zero (to fix the coördinates) at the time one hour after the twist ϕ has been imparted. This is the best conveniently available method for comparing the divers data. Other methods would have compelled us to wait for the subsidence of motion, certainly several months in each case. Moreover, to obtain extreme degrees of accuracy, it is necessary to study viscosity under circumstances of constant temperature, and in a place where the viscous yielding may proceed unaccompanied by tremor or vibratory motion of the apparatus. For these nice experiments we are not now prepared.

The tables furthermore contain the date, the number of hours (h_0) elapsed since the beginning of the experiment and the arbitrary deflection, φ (radians per centimeter of bifilar length),* for each of the times specified. The radius of the wires is given under ρ. Finally the sense of the couples actuating the bifilar body is indicated by τ (torsion), b (bifilar), f (flexure).

TABLE 1.—APPARATUS I.

R=217^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 47, glass-hard, ψ=−180°; No. 48, glass-hard, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$	Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$
21/8, 6^h 08^m	(*)	0·00	(*)	25/8, 9^h 05^m	0·615	91·92	0·156
6 21	0 438	0·22	−0·030	7 01	0·632		
7 08	0·468	1·00	+0·000	26/8, 9^h 10^m	0·653	114·52	0·194
22/8, 9^h 57^m	0·543	15·82	0·075	4 08	0·670		
5 58	0·552	23·83	0·084	27/8, 9^h 11^m	0·695	140·26	0·237
6 54	0·555	24·77	0·087	7 36	0·714		
23/8, 9^h 08^m	0·568	39·00	0·100	28/8, 9^h 21^m	0·734	164·00	0·276
12 31	0·572	42·38	0·104	6 55	0·755		
5 37	0·577	47·48	0·109	29/8, 10^h 12^m	0·780	188·11	0·318
24/8, 9^h 17^m	0·588	67·12	0·126	6 17	0·792		
5 13	0·600						

* Adjusted $\tau - b - f$.

* In practice ϕ is the angle between the normals of the upper and lower mirror divided by the efficient length of wire.

TABLE 2.—APPARATUS II.

R=203^{cm}; L=26^{cm}; l<0·2^{cm}. Rods: No. 1, glass-hard, ψ=+180°; No. 2, glass-hard, ψ=−180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^6$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
11/6, 4^h 30^m	(*)	0·00	(*)	12/6, 8^h 35^m	1·920	16·08	0·015
5 00	1·896	0·50	−0·009	9 25	1·922	16·92	0·017
5 30	1·905	1·00	±0·000	10 10	1·922	17·67	0·017
6 15	1·909	1·75	+0·004	1 5	1·926	20·58	0·021
7 00	1·910	2·50	0·005	2 20	1·926	21·83	0·021
7 33	1·913	3·06	0·008	5 00	1·926	24·50	0·021
				5 50	1·926	25·33	0·021
				8 30	1·926	28·00	0·021
				13/6, 8^h 30^m	1·926	40·00	0·021

* Adjusted $\tau-b-f$.

TABLE 5.—APPARATUS I.

R=209^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 3, glass-hard, ψ=−180°; No. 4, annealed, 100°, 10^h, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
24/6, 8^h 30^m	(*)	0·00	(*)	26/6, 8^h 23^m	0·755	47·88	0·561
9 00	0·139	0·50	−0·055	12 04	0·767	51·57	0·573
9 30	0·194	1·00	±0·000	3 17	0·778	54·78	0·584
10 56	0·277	2·43	+0·083	6 50	0·792	58 33	0·598
11 49	0·312	3·32	0·118	27/6, 8^h 50^m	0·825	72·33	0·631
12 37	0·338	4·12	0 144	3 04	0·834	78·57	0·640
1 52	0·373	5·37	0·179	28/6. 8^h 9^m	0·857	95·65	0·663
3 15	0·401	6·75	0·207	11 29	0·857	98 98	0·663
4 01	0·418	7·52	0·224	5 22	0·859	104·87	0·665
4 55	0·433	8·42	0·239				
6 5	0·453	9·58	0·259	29/6, 8^h 7^m	0·864	118·63	0·670
25/6, 8^h 41^m	0·619	24·18	0·425				
11 35	0·640	27·08	0·446				
5 25	0·682	32·92	0·488				
6 58	0·692	34·47	0·498				

* Adjusted $\tau-b-f$.

TABLE 5A.—APPARATUS I.

R=217^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 43, glass-hard, ψ=−180°; No. 44, annealed 100°, 9^h, ψ=+180°. 2ρ=0·082.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10_2$
8/8, 5^h 00^m	(*)	0·00	(*)	14/8, 9^h 11^m	−0·447	140·19	1·618
5 17	1·265	0·28	−0·125	5 12	−0·509		
6 17	1·127	1·28	+0·013	15/8, 1^h 34^m	−0·635	167·07	1·790
7 33	1·043	2·55	+0 097	6 35	−0·664		
9/8, 9^h 05^m	0·736	16·08	0·404	16/8, 1^h 27^m	−0·755	191·18	1·909
11 56	0·686	18·93	0·454	6 55	−0·783		
1 06	0·664	20·10	0·476	17/8, 9^h 22^m	−0·858	213·15	2·028
7 05	0·579	26·08	0·561	6 55	−0·918		
10/8, 10^h 02^m	0·427	41·03	0·713	18/8, 9^h 15^m	−0·984	236·36	2·139
1 19	0·388	44·32	0·752	5 29	−1·015		
6 20	0·333	49·33	0·807	19/8, 9^h 03^m	−1·066	260·82	2·220
11/8, 10^h 06^m	0·184	69·15	1·001	6 35	−1·094		
1 15	0·147			20/8, 9^h 16^m	−1·136	285·00	2·289
7 06	0·085			6 44	−1·162		
12/8, 9^h 22^m	−0·042	92·43	1·220	21/8, 9^h 07^m	−1·196	304·12	2·336
5 30	−0·117						
13/8, 9^h 09^m	−0·245	116·10	1·422				
1 28	−0·285						
4 41	−0·316						

* Adjusted, $\tau+b+f$.

TABLE 6.—APPARATUS II.

R=203^{cm}; L=26^{cm}; l<0·2^{cm}. Rods: No. 5, glass-hard, ψ=−180°; No. 6, annealed 100°, 9^h, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date	$\phi\times10^3$	h_0	$\phi_0\times10^3$
13/6, 9^h 15^m	(*)	0·00	(*)	14/6, 9^h 00^m	2·393	23·75	0·486
10 15	1·907	1·00	0·000	10 30	2·401	25·25	0·494
11 15	2·031	2·00	0·124	1 3	2·407	27·80	0·500
12 05	2·100	2·83	0·193	2 6	2·409	28·85	0·502
1 25	2·162	4·17	0·255	3 50	2·409	30 58	0·502
3 16	2·247	6·02	0·340	5 27	2·412	32·20	0·505
5 05	2·296	7.83	0·389	† 6 53	2·412	33·60	0·505
6 50	2·345	9·58	0·438				
7 30	2·358	10·25	0·451				

* Adjusted, $\tau-b-f$. † Subequent movement apparently retrograde.

TABLE 6A.—APPARATUS II.

R=202^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 45, glass-hard, ψ=−180°; No. 46, annealed, 100°, 10^h, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
8/8, 6^h 10^m	(*)	0·00	(*)	14/8, 9^h 11^m	0·440	139·03	1·020
6 19	1·502	0·15	−0·062	5 12	0·399		
7 32	1·422	1·37	+0·018	15/8, 1^h 34^m	0·316	165·91	1·133
9/8, 9^h 55^m	1·195	15·75	0·245	6 35	0·298		
12 31	1·169	18.35	0·271	16/8, 1^h 27^m	0·234	190 02	1·218
7 52	1·098	25·70	0·342	6 55	0·211		
10/8, 10^h 02^m	1·007	39·87	0·433	17/8, 9^h 22^m	0·163	211·98	1·299
1 19	0·993	43·15	0·447	6 55	0·119		
6 19	0·948	48·15	0·492	18/8, 9^h 15^m	0·070	235·20	1·382
11/8, 10^h 45^m	0·853	68·19	0·615	5 29	0·046		
1 14	0·833			19/8, 9^h 03^m	0·007	259·65	1·440
7 05	0·789			6 35	−0·008		
12/8, 9^h 22^m	0·709	91·26	0·756	20/8, 9^h 16^m	−0·040	283·83	1·488
5 30	0·658			6 44	−0·056		
13/8, 9^h 09^m	0·576	114·93	0·891				
1 28	0·544						
4 41	0·526						

* Adjusted, $\tau+b+f$.

TABLE 7.—APPARATUS III.

R=400^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 7, glas-shard, $\psi=-180°$; No. 8, annealed, 100°, 10^h, $\psi=+180°$. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
1/7, 12^h 40^m	(*)	0·00	(*)	6/7, 8^h 40^m	1·890	120·61	1·137
1 20	3·122	0·67	−0·128	1 53	1·854		
2 45	2·994	2·08	±0·000	5 16	1·826		
3 25	2·956	2·76	+0·038	7/7, 8^h 53^m	1·730	144·55	1·300
4 37	2·903	3·95	0·091	1 30	1·691		
5 39	2·869	4·98	0·125	5 16	1·660		
6 59	2·832	6·32	0·162	8/7, 9^h 16^m	1·547	168·59	1·485
2/7, 9^h 22^m	2·627	20·70	0·367	12 43	1·515		
1 46	2·578	25·10	0·416	5 48	1·465		
5 11	2·554	28·52	0·440	9/7, 8^h 35^m	1·366	192·02	1·657
3/7, 8^h 20^m	2·435	43·67	0·559	12 11	1·339		
12 14	2·397	47·57	0·597	5 18	1·307		
6 30	2·331	53·83	0·663	10/7, 8^h 07^m	1·225	215·87	1·798
4/7, 9^h 47^m	2·233	73·10	0·800	12 09	1·200		
12 09	2·208			5 20	1·162		
3 08	2·183			11/7, 9^h 08^m	1·080	236·47	1·914
6 00	2·153						
5/7, 8^h 40^m	2·061	95·80	0·965				
12 00	2·033						
4 44	1·992						

* Adjusted, $\tau+b+f$.

TABLE 8.—APPARATUS IV.

R=308^{cm}; L=26^{cm}; l<0·2^{cm}. Rods: No. 9, glass-hard, $\psi=-180°$; No. 10, annealed, 100°, 10^h, $\psi=+180°$. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
1/7, 1^h 40^m	(*)	0·00	(*)	5/7, 8^h 41^m	1·876	94·81	0·718
2 46	1·185	1·10	0·000	12 00	1·899		
3 26	1·213	1·77	0·028	4 45	1·935		
4 39	1·246	2·82	0·061	6/7, 8^h 42^m	2·027	119·63	0·874
5 40	1·265	4·00	0·080	1 54	2·063		
7 00	1·290	5·33	0·105	5 17	2·088		
2/7, 9^h 23^m	1·420	19·72	0·236	7/7, 8^h 54^m	2·185	143·58	1·034
1 48	1·459	24·13	0·274	1 32	2·222		
5 12	1·482	28·53	0·297	5 18	2·249		
3/7, 8^h 22^m	1·577	42·70	0·392	8/7, 9^h 18^m	2·362	167·61	1·206
12 15	1·605	46·58	0·420	12 43	2·385		
6 30	1·641	52·83	0·456	5 49	2·427		
4/7, 9^h 49^m	1·729	72·12	0·574	9/7, 8^h 37^m	2·524	191·04	1·366
12 10	1·747			12 11	2·547		
3 09	1·770			5 19	2 581		
6 01	1·791			10/7, 8^h 07^m	2·655	210·45	1·470

* Adjusted, $\tau-b-f$

TABLE 10.—APPARATUS II.

R=200^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 11, glass-hard, ψ=−180°; No. 12, annealed, 190°, 2^h, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
1/7, 4^h 00^m	(*)	0·00	(*)	2/7, 9^h 20^m	2·215	17·33	0·625
4 35	2·913	0·58	−0·073	1 45	2·133	21·75	0·707
5 36	2·767	1·60	+0·073	5 09	2·080	25·15	0·760
6 58	2·655	2·97	0·185	3/7, 8^h 19^m	1·891	40·32	0·949
				12 12	1·843	44·20	0·997
				6 28	1·757	50·47	1·083

* Adjusted, $\tau+b+f$.

TABLE 13.—APPARATUS III.

R=370^{cm}; L=26^{cm}; l<0·2^{cm}. Rods: No. 13, glass-hard, ψ=−180°; No. 14, annealed, 190°, 1^h; ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10_0$
14/6, 12^h 30^m	(*)	0·00	(*)	21/6, 8^h 22^m	3·732	169·91	2·692
1 10	1·025	0·67	−0·065	12 15	3·763		
2 05	1·198	1·58	+0·108	5 44	3·810		
3 51	1·402	3·35	0·312	†7 17	3·823		
4 21	1·448	3·85	0·358	22/6, 9^h 10^m	3·913	193·38	2·856
5 29	1.525	4·98	0·435	1 18	3·943		
6 55	1·606	6·42	0·516	2 20	3·948		
7 51	1·648	7·35	0·558	6 42	3·980		
15/6, 9^h 04^m	2·022	20·57	0·932	23/6, 8^h 30^m	4·056	214·86	2·971
10 00	2·042	21·50	0·952	12 43	4·077		
11 15	2·073	22·75	0·983	5 42	4·111		
1 10	2·121	24·67	1·031	24/6, 9^h 02^m	4·197	240·38	3·132
2 58	2·165	26·47	1·075	12 39	4·222		
4 17	2·195	27·78	1·105	4 58	4·248		
5 41	2·223	29·18	1·133	25/6, 8^h 44^m	4·335	264·13	3·266
6 18	2·233	29·80	1·143	11 38	4·351		
16/6, 8^h 00^m	2·467	48·26	1·460	†5 31	4·383		
9 32	2·492			26/6, 8^h 29^m	4·448	289·18	3·385
1 07	2·556			12 10	4·467		
3 19	2·597			3 12	4·483		
5 50	2·638			6 52	4·504		
17/6, 8^h 34^m	2·861	73·43	1·878	27/6, 8^h 52^m	4·575	311·49	3·502
10 29	2·899			3 06	4·609		
12 43	2·942			28/6, 8^h 11^m	4·699	335·87	3·631
3 35	2·995			11 30	4·720		
5 29	3·043			5 25	4·744		
6 45	3·066			29/6, 8^h 11^m	4·811	361·44	3·754
18/6, 11^h 45^m	3·236	99·02	2·181	3 46	4·854		
4 39	3·283			5 52	4·866		
†6 09	3·293			30/6, 8^h 53^m	4·943	384·41	3·872
19/6, 9^h 07^m	3·410	120·92	2·346	12 26	4·962		
12 19	3·432			5 25	4·982		
2 25	3·445			1/7, 8^h 47^m	5·028	404·28	5·028
5 50	3·458						
20/6, 8^h 53^m	3·567	145·23	2·515				
10 53	3·581						
3 26	3·622						
7 44	3·652						

* Adjusted, $\tau-b-f$. † Re-adjusted after this observation.

TABLE 13A.—APPARATUS III.

R=400^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 19, glass-hard, $\psi=-180°$; No. 20, annealed, 190°, 1^h, $\psi=+180°$. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
11/7, 3^h 20^m	(*)	0·00	(*)	15/7, 10^h 46^m	1·491	94·27	2·013
4 10	−0·037	0·83	−0·037	4 26	1·548		
4 20	±0·000	1·00	±0·000	16/7, 9^h 18^m	1·695	118·32	2·232
5 22	+0·161	2·03	+0·161	1 44	1·740		
7 00	0·329	3·67	0·329	5 55	1·780		
12/7, 7^h 37^m	0·913	16·28	0·913	17/7, 8^h 47^m	1·899	141·90	2·438
7 55	†	16·58	†	12 53	1·940		
9 02	0·466	17·70	0·960	6 02	1·992		
10 55	0·523	19·58	1·017	18/7, 8^h 44^m	2·096	164·25	2·617
5 27	0·696	26·12	1·190	2 26	2·151		
13/7, 8^h 29^m	0·952	41·15	1·446	19/7, 9^h 39^m	2·304	189·73	2·829
12 29	0·999	45·15	1·493	12 20	2·331		
5 08	1·061	49·80	1·555	5 12	2·371		
14/7, 8^h 54^m	1·230	69·49	1·765				
12 51	1·270						
4 41	1·314						

* Adjusted $\tau+b+f$. † Adjusted $\tau-b-f$.

TABLE 14.—APPARATUS IV.

R=300^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 15, glass-hard, $\psi=-180°$; No. 16, annealed, 190°, 1^h, $\psi=+180°$. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$_0\phi\times10^3$
11/7, 4^h 25^m	(*)	0·00	(*)	16/7, 9^h 19^m	1·849	117·26	1·919
4 42	−0·210	0·28	−0·175	1 45	1·885		
4 55	−0·143	0·50	−0·108	5 58	1·917		
5 25	−0·035	1·00	±0·000	17/7, 8^h 49^m	2·022	140·84	2·093
7 00	+0·153	2·58	+0·188	12 54	2·052		
12/7, 7^h 38^m	0·685	15·22	0·720	6 03	2·099		
5 28	0·937	25·05	0·972	18/7, 8^h 45^m	2·198	163·35	2·256
13/7, 8^h 29^m	1·179	40·07	1·214	2 47	2·243		
12 29	1·222	44·07	1·257	19/7, 9^h 40^m	2·378	188·66	2·444
5 09	1·280	48·73	1·315	12 21	2·419		
14/7, 8^h 54^m	1·434	68·40	1·508	5 13	2·429		
12 52	1·473			20/7, 8^h 32^m	2·517	209·68	2·562
4 42	1 512			11 40	2·538		
15/7, 10^h 47^m	1·670	93·20	1·730				
4 26	1·720						

* Adjusted $\tau-b-f$.

TABLE 16.—APPARATUS II.

$R=200^{cm}$; $L=27^{cm}$; $l<0{\cdot}2^{cm}$. Rods: No. 17, glass-hard, $\psi=-180°$; No. 18, annealed, 350°, 1^h, $\psi=+180°$. $2\rho=0{\cdot}082^{cm}$.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
4/7, $10^h\,35^m$	(*)	0·00	(*)	10/7, $8^h\,05^m$	0·545	145·93	3·092
$10\;53$	−2·767	0·30	−0·267	$12\;08$	0·589		
$12\;08$	−2·457	1·55	+0·043	$5\;19$	0·643		
$3\;07$	−2·118	4·53	0·382	11/7, $9^h\,08^m$	0·797	171·67	3·348
$5\;59$	−1·929	7·40	0·570	$11\;34$	0·821		
5/7, $8^h\,39^m$	−1·423	22·07	1·076	$5\;21$	0·881		
$11\;59$	−1·318	25·40	1·181	$6\;59$	0·892		
$5\;43$	−1·187	31·13	1·312	12/7, $7^h\,36^m$	0·993	193·93	3·533
6/7, $8^h\,40^m$	−0·882	46·08	1·617	$5\;26$	1·072		
$1\;52$	−0·773	51·28	1·726	13/7, $8^h\,27^m$	1·163	218·10	3·686
$5\;15$	−0·703	54·67	1·796	$12\;27$	1·180		
7/7, $8^h\,50^m$	−0·455	74·59	2·127	$5\;08$	1·215		
$1\;26$	−0·367			14/7, $8^h\,53^m$	1·299	242·20	3·823
$5\;15$	−0·295			$12\;48$	1·323		
8/7, $9^h\,15^m$	−0·056	98·66	2·513	$4\;40$	1·348		
$12\;42$	+0·007			15/7, $10^h\,45^m$	1·446	267·00	3·965
$5\;47$	0·089			$4\;25$	1·483		
9/7, $8^h\,34^m$	0·274	122·09	2·826	16/7, $9^h\,17^m$	1·565	286·70	4·065
$12\;10$	0·321						
$5\;17$	0·383						

* Adjusted $\tau-b-f$.

TABLE 18.—APPARATUS IV.

$R=316^{cm}$; $L=26^{cm}$; $l<0{\cdot}2^{cm}$. Rods: No. 21, glass-hard, $\psi=-180°$; No. 22, annealed, 360°, 1^h, $\psi=+180°$. $2\rho=0{\cdot}082^{cm}$.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
14/6. $2^h\,45^m$	(*)	0·00	(*)	17/6, $8^h\,35^m$	3·302	71·19	2·296
$3\;52$	1·155	1·12	0·025	$10\;30$	3·349		
$4\;22$	1·250	1·62	0·120	$12\;44$	3·405		
$5\;30$	1·415	2·75	0·285	$3\;36$	3·465		
$6\;55$	1·558	4·17	0·428	$5\;30$	3·503		
$7\;53$	1·632	5·13	0·502	$6\;45$	3·531		
15/6, $9^h\,05^m$	2·198	18·33	1·068	18/6, $8^h\,53^m$	3·741	95·12	2·667
†$10\;00$	2·231	19·25	1·101	$11\;45$	3·770		
$11\;16$	2·273	20·52	1·143	$4\;40$	3·829		
$1\;11$	2·340	22·43	1·210	†$6\;10$	3·850		
$3\;00$	2·400	24·25	1·270	19/6, $9^h\,09^m$	4·000	118·69	2·904
$4\;16$	2·442	25·57	1·312	$12\;19$	4·026		
$5\;42$	2·478	26·95	1·348	$2\;27$	4·037		
$6\;19$	2·490	27·57	1·360	$5\;51$	4·071		
16/6, $8^h\,02^m$	2·802	46·03	1·785	20/6, $8^h\,54^m$	4·193	143·01	3·105
$9\;33$	2·837			$10\;59$	4·211		
$1\;09$	2·928			$3\;25$	4·250		
$3\;20$	2·978			$7\;45$	4·286		
$5\;50$	3·028						

* Adjusted $\tau-b-f$. † Re-adjusted.

TABLE 18.—Concluded.

Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$	Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$
21/6, 8h 23m	4·374	167 66	3·290	26/6, 8h 30m	5·143	286·87	4·048
12 15	4·403			*1 28	5·177		
5 45	4·447			6 53	5·213		
7 16	4·456			27/6, 8h 53m	5·303	309·25	4·196
22/6, 9h 11m	4·541	191·61	3·434	3 07	5·350		
1 19	4·558			28/6, 8h 13m	5·450	333·64	4·346
4 13	4·573			11 31	5·471		
6 43	4·583			5 26	5·508		
23/6, 8h 30m	4·666	214·22	3·569	29/6, 8h 12m	5·595	359·19	4·505
12 43	4·699			3 45	5·647		
5 42	4·732			5 53	5·662		
24/6, 9h 03m	4·829	238·15	3·722	30/6, 8h 54m	5·740	382·18	4·629
12 40	4·853			12 27	5·757		
4 59	4·873			5 26	5·780		
25/6, 8h 45m	4·973	261·88	3·875	1/7, 8h 48m	5·848	402·05	5·848
11 39	4·997						
5 30	5·044						

* Re-adjusted.

TABLE 19.—APPARATUS I.

R=217cm; L=26cm; l<0·2cm. Rods: No. 23, glass-hard, ψ=−180°; No. 24, annealed, 450°, 1h, ψ=+180°. 2ρ=0·082cm.

Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$	Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$
21/7, 2h 50m	(*)	0·00	(*)	29/7, 8h 56m	−0·673	189·80	3·814
3 17	3·276	0·45	−0·176	12 36	−0·714		
4 44	2·901	1·90	+0·198	4 22	−0·758		
5 21	2·805	2 52	0·294	30/7, 8h 52m	−0·937	213·85	4·085
6 13	2·698	3·38	0·401	1 05	−0·991		
22/7, 8h 40m	1·924	17·83	1·175	4 07	−1·030		
11 58	1·798	21·13	1·301	31/7, 9h 28m	−1·210	237·82	4·345
5 30	1·606	26·67	1·493	12 36	−1·249		
7 10	1·552	28·33	1·547	3 55	−1 281		
23/7, 7h 49m	1·307	40·98	1·792	2/8, 9h 38m	−1·639	286·13	4·768
12 30	1·141	45·67	1·958	1 11	−1·672		
3 31	1·072	48·68	2·027	4 05	−1·696		
24/7, 9h 13m	0·769	69·91	2·393	3/8, 9h 38m	−1·807	310·22	4·926
12 52	0·702			1 14	−1·826		
4 10	0·647			4 18	−1·844		
26/7, 8h 53m	0·126	117·40	3·019	4/8, 1h 31m	−1·947	336·12	5·055
12 07	0·081			4 23	−1·962		
3 42	0·033			5/8, 1h 36m	−2·052	360·67	5·162
27/7, 8h 49m	−0·146	141·60	3·290	5 25	−2·073		
12 26	−0·193			6/8, 9h 12m	−2·139	382·48	5·257
4 04	−0·235			5 26	−2·175		
28/7, 9h 11m	−0·423	166·03	3·564	7/8, 9h 15m	−2·225	407·13	5·346
1 07	−0·468			6 41	−2·268		
4 17	−0·503						

* Adjusted $\tau+b+f$.

TABLE 20.—APPARATUS II.

R=198^{cm}; L=26^{cm}; l<0·2^{cm}. Rods; No. 25, glass-hard, ψ=−180°; No. 26, annealed, 450°, 1^h, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
15/6, 12^h 50^m	(*)	0·00	(*)	21/6, 8^h 20^m	5·364	145·55	3·177
1 07	1·968	0·28	−0·282	12 15	5·401		
1 15	2·046	0·42	−0·204	†5 40	5·466		
1 30	2·152	0·67	−0·098	7 19	5·478		
1 45	2·239	0·92	−0·011	22/6, 9^h 08^m	5·573	169·47	3·355
2 55	2·475	2·08	+0·225	1 16	5·597		
4 15	2·648	3·42	0·398	4 10	5·617		
5 39	2·776	4·82	0·526	6 40	5·632		
6 17	2·825	5·45	0·575	23/6, 8^h 27^m	5·717	192·10	3·499
16/6, 7^h 56^m	3·447	19·10	1·197	12 40	5·748		
9 30	3·506	20·67	1·256	5 41	5·781		
1 06	3·632	24·27	1·382	24/6, 9^h 00^m	5·880	216·01	3·660
3 17	3·703	26·45	1·453	12 37	5·909		
5 49	3·780	28·98	1·530	4 55	5·941		
17/6, 8^h 33^m	4·134	49·06	2·035	25/6, 8^h 42^m	6·045	239·76	3·820
10 26	4·191			11 36	6·068		
12 41	4·258			5 28	6·111		
3 31	4·337			26/6, 8^h 27^m	6·206	264·29	3·989
5 26	4·378			12 05	6·227		
6 44	4·410			6 50	6·283		
18/6, 8^h 48^m	4·656	72·98	2·471	27/6, 8^h 51^m	6·367	287·11	4·140
11 43	4·690			3 02	6·412		
4 38	4·759			28/6, 8^h 08^m	6·516	311·51	4·326
6 07	4·778			11 29	6·535		
19/6, 9^h 05^m	4·953	96·53	2·741	5 24	6·678		
12 10	4·982			29/6, 8^h 09^m	6·662	337·07	4·451
2 23	4·998			3 43	6·714		
5 50	5·031			5 50	6·728		
20/6, 8^h 12^m	5·170	120·71	2·963	30/6, 8^h 52^m	6·811	350·08	4·577
10 52	5·179			12 29	6 825		
3 24	5·232			5 24	6·845		
7 42	5·270			1/7, 8^h 39^m	6·910	379·82	4·660

* Adjusted, $\tau-b-f$. † Re-adjusted.

TABLE 23.—APPARATUS I.

R=215^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 27, glass-hard, ψ=−180°; No. 28, soft, ψ=+180°. 2ρ=0·082.

Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$	Date.	$\phi \times 10^3$	h_0	$\phi_0 \times 10^3$
9/6, 2^h 30^m	(*)	0·00	(*)	14/6, 9^h 04^m	4·736		
3 10	1·652	0·67	−0·118	10 30	4·757	120·33	3·046
3 13	1·677	0·71	−0·093	1 00	4·796		
3 21	1·730	0·85	−0·040	2 06	4·813		
3 47	1·860	1·28	+0·090	3 50	4·836		
4 00	1·910	1·50	0·140	5 27	4·853		
4 10	1·940	1·67	0·170	6 52	4·866		
4 32	2·004	2·03	0·234	7 50	4·873		
5 15	2·102	2·75	0·332	15/6, 9^h 00^m	4·990	143·30	3·272
5 35	2·140	3·08	†0·370	10 00	4·998		
6 00	2·185	3·50	0·415	11 15	5·015		
6 15	2·210	3·75	0·440	1 05	5·037		
10/6, 8^h 50^m	2·938	20·09	1·227	2 55	5·060		
9 35	2·964			4 15	5·071		
9 55	2·973			5 38	5·082		
10 15	2·985			6 15	5·086		
10 45	3·002			16/6, 7^h 58^m	5·205	166·22	3·488
11 20	3·023			9 30	5·223		
11 45	3·038			1 05	5·265		
12 17	3·056			3 15	5·285		
10/6, 1^h 30^m	3·100	26·64	1·448	5 48	5·310		
2 15	3·128			17/6, 8^h 30^m	5·455	191·54	3·758
3 05	3·153			10 26	5·485		
4 00	3·191			12 40	5·520		
4 40	3·214			3 30	5·550		
5 25	3·238			5 27	5·570		
6 25	3·265			7 43	5·590		
†7 40	3·287			18/6, 8^h 46^m	5·705	215·31	3·970
8 05	3·296			11 43	5·720		
8 20	3·304			4 37	5·760		
11/6, 8^h 06^m	3·542	47·34	1·895	6 08	5·775		
9 28	3·571			19/6, 9^h 04^m	5·880	238·52	4·125
10 21	3·588			12 09	5·890		
10 45	3 598			5 50	5·915		
11 45	3·617			20/6, 8^h 50^m	6·010	263·18	4·272
12 11	3·628			10 50	6·023		
2 30	3·680			3 23	6·055		
3 48	3·709			7 40	6·080		
4 50	3·733			21/6, 8^h 20^m	6·140	287·88	4·408
5 50	3·753			12 15	6·160		
7 00	3·777			5 38	6·200		
7 35	3·787			7 19	6·210		
12/6, 8^h 37^m	3·989	71·44	2·318	22/6, 9^h 07^m	6·270	311·80	4·525
9 25	4·005			1 16	6·290		
10 10	4·017			4 09	6·305		
1 05	4 076			6 40	6·315		
2 55	4·108			23/6, 8^h 28^m	6·375	334·44	4·633
4 58	4·146			12 40	6·405		
5 50	4·162			5 40	6·430		
8 30	4·202						
13/6, 8^h 40^m	4·376	95·89	2·702				
10 15	4·405						
12 06	4·436						
1 25	4·458						
3 16	4·485						
5 07	4·517						
6 50	4·545						
7 30	4·556						

* Adjusted, $\tau-b-f$.

† Re-adjusted.

TABLE 24.—APPARATUS II.

R=202^{cm}; L=28^{cm}; l<0·2^{cm}. Rods: No. 29, glass-hard, ψ=−180°; No. 30, commercial, drawn, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
21/7, 10^h 45^m	(*)	0·00	*	29/7, 8^h 56^m	−0·709	193·90	3·012
11 59	2·263	1·08	0·000	12 39	−0·749		
12 18	2·206	1·55	0·057	4 23	−0·788		
2 03	2 045	3·30	0·218	30/7, 8^h 54^m	−0·957	217·96	3·269
3 52	1·926	5·12	0·337	1 06	−1·010		
5 22	1·847	6·62	0·416	4 07	−1·050		
22/7, 8^h 40^m	1·416	21·92	0·847	31/7, 9^h 42^m	−1 230	242·01	3·526
11 58	1·341	25·22	0·922	12 37	−1·263		
5 31	1·217	30·77	1·046	3 57	−1·297		
7 44	1·187	32·98	1·076	2/8, 9^h 39^m	−1·644	290·23	3·934
23/7, 7^h 50^m	0·984	45·08	1·279	1 12	−1·677		
12 32	0·896	49·78	1·367	4 06	−1·693		
3 33	0·851	52·80	1·412	3/8, 9^h 40^m	−1·780	314·33	4·049
24/7, 9^h 16^m	0 624	74·03	1·737	1 15	−1·784		
12 53	0·499			4 19	−1·793		
4 12	0·456			4/8, 1^h 32^m	−1·872	340·22	4·139
26/7, 8^h 55^m	−0·025	121·53	2·292	4 24	−1·880		
12 08	−0·011			5/8, 1^h 37^m	−1·965	364·77	4·237
3 47	−0·051			5 25	−1·982		
27/7, 8^h 51^m	−0·211	145·71	2·516	6/8, 9^h 13^m	−2·044	386·59	4·324
12 27	−0·255			5 27	−2·078		
4 05	−0·293			7/8, 9^h 17^m	−2·133	411·24	4·412
28/7, 9^h 20^m	−0·487	170·18	2·781	6 42	−2·165		
1 09	−0·517						
4 18	−0·550						

* Adjusted, $\tau+b+f$.

TABLE 25.—APPARATUS III.

R=370^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 31, glass-hard, ψ=−180°; No. 32, commercial, softened, ψ=+180°. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
22/7, 9^h 00^m	(*)	0·00	(*)	27/7, 8^h 54^m	−2·305	123·51	3·055
9 08	0·949	0·13	−0·249	12 30	−2·356		
11 59	0·331	2·98	+0·368	4 08	−2·404		
5 32	0·099	8·53	0·600	28/7, 9^h 26^m	−2·612	147.98	3·355
7 11	−0·193	10·18	0·893	1 11	−2·658		
23/7, 7^h 52^m	−0 643	22·87	1·343	4 20	−2·695		
12 35	−0·794	27·58	1·494	29/7, 8^h 59^m	−2·875	171·72	3·624
3 25	−0·880	30·42	1·580	12 42	−2·923		
24/7, 9^h 21^m	−1·246	48·35	1·946	4 28	−2·974		
12 57	−1·320	51·95	2·020	30/7, 8^h 57^m	−3·160	195·80	3·913
4 16	−1·384	55·27	2·084	1 10	−3·217		
26/7, 8^h 57^m	−1·993	99·31	2·749	4 17	−3·261		
12 10	−2·050						
3 49	−2·105						

* Adjusted $\tau+b+f$.

TABLE 26.—APPARATUS IV.

R=314^{cm}; L=27^{cm}; l<0·2^{cm}. Rods: No. 33, glass-hard, $\psi=-180°$; No. 34, annealed at 1000°, $\psi=+180°$. 2ρ=0·082^{cm}.

Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$	Date.	$\phi\times10^3$	h_0	$\phi_0\times10^3$
21/7, 4^h 15^m	(*)	0·00	(*)	29/7, 9^h 02^m	−2·324	189·18	3·467
4 43	1·249	0·47	−0·149	12 45	−2·367		
5 23	1·089	1·13	+0·010	4 31	−2·409		
5 45	1·022	1·50	0·077	30/7, 9^h 00^m	−2·583	212·61	3·730
6 12	0·957	1·95	0·142	1 13	−2·633		
22/7, 8^h 42^m	0·162	16·45	0·937	4 22	−2·673		
12 00	0·042	19·75	1·057	31/7, 9^h 52^m	−2·850	236·61	3·982
5 33	−0·250	25·30	1·249	12 41	−2·882		
7 12	−0·185	26 95	1·284	4 01	−2·912		
23/7, 7^h 53^m	−0·448	39·63	1·547	2/8, 10 ^{h}02^m	−3·264	284·95	4·389
12 36	−0 559	44·35	1·658	1 24	−3·291		
3 36	−0·628	47·35	1·727	4 10	−3·312		
24/7, 9^h 23^m	−0·024	68·64	2·082	3/8, 9^h 47^m	−3·423	308.93	4·534
12 59	−0·985			1 22	−3·436		
4 19	−1·038			4 24	−3·442		
26/7, 9^h 05^m	−1·540	116·14	2·685	4/8, 1^h 38^m	−3·548	334·78	4·654
12 14	−1·581			4 26	−3·560		
3 52	−1·643			5/8, 1^h 40^m	−3·660	359·31	4·768
27/7, 9^h 03^m	−1·807	140·35	2·951	5 27	−3·675		
12 34	−1·851			6/8, 9^h 14^m	−3·733	381·10	4·855
4 10	−1·895			5 28	−3·777		
28/7, 9^h 29^m	−2·081	164·79	3·222	7/8, 9^h 22^m	−3·829	405·80	4·946
1 16	−2·125			6 43	−3·863		
4 23	−2·159						

* Adjusted $\tau+b+f$.

Remarks on the Tables.—In experimenting with couples of two glass-hard wires, or with couples in which one of the wires is annealed at 100°, the degree of hardness of the harder wire is an exceedingly important factor. Hence these curves (tables 5, 5A, 6, 6A, 7, 8) appear under a variety of forms. Only tables 5A, 6A, 7, 8 are used in the digest constructed below. The results in tables 19, 24, 26 change their curvature after August 1st. Since the same error is found in all the wires then examined it is probably a result of temperature. When minutely examined (cf. table 23, for instance), the curves show a sinuous outline which is quite marked and probably also due to temperature, or to tremors. If the curves for stated temperatures and times of annealing fail to coincide it is due to differences in the tempers of the glass-hard wires, to similar differences in the tempers of the annealed wires, to preëxisting strains accidentally imparted to one wire or the other, to lack of perfect uniformity of temper throughout the efficient lengths, to unavoidable inequalities of the sectional areas of the pairs of wires. The last-named error probably also effects the curvature. Viscous rotation of the arms which carry the mir-

rors, or yielding of the cement, is nil and is not to be apprehended, since the fixed mirror is a fiducial mark for the movable mirror. In the above work we do not indicate the amount of permanent torsion left in each wire after the experiment is finished. Though an important desideratum, it does not fall within the scope of this paper. The effect of temperature on twisted systems of pairs of identical steel wires we shall probably investigate later and then discuss the amount of detorsion due to annealing at stated temperatures and times. The soft ends introduce no serious error because soft steel is more viscous than hard steel. The amount of twist registered is that between the upper and lower points of attachment. The included wires must be of uniform hardness.

The fact that an effect of the bifilar and flexural components is wholly absent in these results is proved by table 13A, in which the curve for $\tau+b+f$ is followed without break of continuity by the curve $\tau-b-f$, and the total curve is practically identical with the locus for table 13. It is proved, moreover, by tables 1, 2, in which couples of glass-hard wires show no greater difference than is at once attributable to unavoidable differences of hardness; and by table 34, in which $\tau+b+f$ and $\tau-b-f$ produce practically identical zero-effects on two soft wires. It is generally proved by the distribution of the 50 rods examined in a diagram of viscosity conformably with the respective tempers of the rods. If a couple of one hard and one soft rod possessed a smaller total of viscosity than a couple of two hard rods, then the bifilar and flexural couples might produce an effect in the former case and not in the latter. The absence of all effect in the case of two soft rods as well as in the case of two hard rods shows that the discrepancy in question is nil. The important bearing of this result will be indicated below.

[To be concluded.]

ART. LIV.—*Some Remarks upon the Journey of André Michaux to the high Mountains of Carolina, in December*, 1788, *in a Letter addressed to Professor Asa Gray;* by C. S. SARGENT.

HAVING recently returned from a somewhat extended excursion through that portion of the mountain region of North and South Carolina which lies about the head waters of the Savannah River,—the scene, I have reason to believe, of André Michaux's perilous and interesting mountain journey made in the winter of 1788–89, and which, so far as I can learn, has not been visited again until this year by a botanical traveler,

—you will permit me, I hope, to invite your attention to a few remarks suggested by my journey. In doing this I venture to remind you of the fact, not without interest to the younger generations of botanists, that it is just forty-five years (or nearly half the century which separates us from the time when André Michaux was engaged in exploring the flora of North America), since you made known to the botanical world through the pages of this Journal some of the results of your first journey in the Carolina Mountains and traced the foot-steps of your botanical predecessor in that field.*

The principal object of Michaux, as will appear later, was to gather living plants of *Magnolia cordata*. This tree, although still preserved and now very generally distributed in gardens, has never so far as I am aware, been found growing naturally since the days of the Michauxs. The object of my journey was to rediscover it, where Michaux was thought to have found it, and so throw some light upon its specific character and geographical distribution. But, before entering upon any discussion of this subject, it is desirable to determine if possible what plant Michaux set out to collect, and the exact region visited by him for this purpose. Fortunately the manuscript diary of Michaux's travels in North America, presented by his son, F. A. Michaux, to the American Philosophical Society, aids us here.

Michaux left Augusta on the 21st of November, 1788. On the 24th he arrived at Washington, in Wilkes County, Georgia, where a serious attack of fever detained him until the 29th. He reached the head of the Savannah River on the second of December and then ascended its western fork, the Tugalo, for several days. Here he secured the services of a Cherokee guide and crossed some of the spurs of the Blue Ridge into the valley of the Keowee River, camping on the banks of that stream on the evening of the 7th. The remainder of his journey will best be described in his own words.

"Le 8 Decembre, 1788, à mesure que nous approchions de la source du Keivi, les chemins devinrent plus difficiles. Notre marche fut de . . . . et deux miles avant d'y arriver je reconnus le *Magnolia montana* qui a été nommé *M. cordata* ou *auriculata* par Bartram. Il y avait en ce lieu une petite cabane habitée par une famille de sauvage Cherokees. Nous nous arretames pour y camper et je courrus faire des recherches. Je recueillis un nouvel arbuste a f. dentelées rampant sur la montagne à peu de distance de la riv. Le temps changea et nous eumes de la pluie toute la nuit, quoique nous fassions a

* Notes of a Botanical Excursion in the mountains of North Carolina, etc., by Asa Gray, M.D., vol. xlii, No. 1, December, 1841.

l'abri d'un gros Pinus Strobus, nos habits, nos couvertures furent trempés et traversés. J'allai vers milieu de la nuit dans la Cabane des sauvages qui pouvait à peine contenir la famille composée de huit personnes, hommes et femmes. Il y avait de plus six gros chiens qui augmentoient la malpropreté de cet appartement et l'incommodité. Le feu etoit placé au mileu sans ouverture au haut de la cabane pour laisser sorter la fumée, il y en avait cependt assez po. recevoir la pluye au travers la couverture de cette maison. Un sauvage m'offrit son Lit qui etait une Peau d'Ours et vint prendre ma place aupres du feu. Mais enfin incommodé par les Chiens qui se mordoient continuellent pour avoir leur place au feu, je retournay au camp, la pluye ayant cessé.

Ce lieu qui l'on nomme la source de Keivi cet ainsi improprement nommé, c'est la junction de deux autres rivi ou gros Torrents qui viennent se revunir en ce lieu et n'ont pas été nommés sinon Branches de Keivi. Le q. nous partimes guide par mon sauvage po. visiter les plus hautes montagnes et aller à la source de ce torrent qui me parut le plus escarpé. Il fallut passer des précipices et des torrents couverts d'arbes ou dix fois nos chevaux s'enfoncerent et furent en danger de perir. Nous remontames jusqu'a une cascade ou la bruit de l'eau en tombant ressemblait a des coups eloignes de Mousquets. Les sauvages disent que l'on voit paroitre en ce lieu des feur la nuit. Je desirai y camper, mais la neige qui survint et le vent etait si froid que nous cherchames le bas d'une montagne moins exposé au froid et un lieu plus garni d'herbes po. nos chevaux. La nuit fut horriblement froide, il n'y avait pas en ce lieu bois de Pin po. entretenir le feu qui brulait mal à cause de la neige qui tomba à plus reprises. Nos couvertures couvertes de neige devenoient roides de gelée peu après avoir été chaufées.

Le 10 Decembre. Je visitay plusi montagnes, sur la pente et dans les lieux bas nous arrachames le *Magnolia cordata* la journee fut employée plus particulierem^{t} à la recherche de cet arbe.

Le onze dud. il gela considerablement et l'air fut clair et tres vif. Je remarquai une suite de hautes montagnes qui se prolongeaient de l'Ouest a l'Est et ou la gelée s'etoit fait peu sentir a l'expositoin du soleil. Je recueillis un Juniperus (repens) que je n'avoir pas encore remarqué dans les parties meridionales des Etats Unis; mais il faut observer que je vis sur ces montagnes plusieurs arbes des parties septentionales telsque le Betula nigra, Cornus alternifolia, Pinus Strobus, Abies, Spruce, etc. Nous traversames un espace d'environ trois miles dans les Rhododendrons maximum. Je reviens camper avec mes quides à la Tête des Keivi (head of Kiwie) et je recueillis une grande quantité de cet arbuste a f. denti-

culées trouvé le jour que j'arrivay. Je ne le rencontray sur aucune des autres montangnes. Les sauvages du lieu me dirent que les feuilles avoient bon gout etant machées et que l'odeur en était agréable en les froissant, ce que ie trouval effectivement.

Direction pour trouver cet arbuste.—La Tête du Keivi est la jonction de deux torrents considerables qui coulent par cascades des hautes montagnes. Cette jonction se fait dans une petite plaine oa il y avait autrefois une ville ou plutot un village de Cherokees. En descendant de la junction de ces deux torrents ayant la rivi à gauche et les montagnes qui regardent le Nord à droite, on trouve à environ 30 à 50 toises de ce confluent un senti formé par les Chasseurs sauvages, il conduit à un ruisseau ou l'on reconnait les vestiges d'un village par les Pèchers qui subsistent au milieu des Brouss. En continuant ce sentier on arrive aussitot sur les montagnes et l'on trouve cet arbuste qui couvre le sol avec l'Epigea repens.

Le 12 Decembre, 1788. Je visitay les montagnes exposées au sud en revenant, car les provisions etoient si avancés, qu'il y eut un Dejeuner trés sobre. Je recueillis beaucoup de *Magn. cordata* en un meilleur état que ceux des jours precedents."

The entry, made in the journal on the 3d of December, suggests that *M. auriculata* (*M. Fraseri* Walter) must have been the object of Michaux's search at this time, and not the *M. cordata* of his flora. The younger Bartram twelve years before had visited the Cherokee country, crossing the mountains on to the waters of the Tennessee River, and had discovered his *Magnolia auriculata* first on the mountains between the Tugalo and the Keowee, and then in greater abundance and perfection on what he supposed was the highest peak of the Cherokee mountains, probably either Hogback or Whiteside, and which he named Mount Magnolia in honor of his discovery.* Michaux doubtless had heard of this new Magnolia at the time of his visit to the Bartrams in 1787, and as his route was now almost identical with that followed by William Bartram, there seems to be little doubt that it was Bartram's Magnolia, and not the *Magnolia cordata* of his flora, which he was in pursuit of. The fact that Michaux mentions in his journal under date of June 14, 1787, when he was on the Keowee River, the discovery of a new Magnolia "que je nomme Magnolia (Hastata)" and which from the locality must have been Bartram's plant, is no reason why a year later he may not have spoken of it as the "mountain Magnolia named by Bartram, *M. cordata ou auriculata.*" This discovery of June 14th, judging from the brief mention in this Journal, made less impression upon Mi-

* William Bartram, Travels; Second edition, p. 337.

chaux than many of his discoveries of new plants, and the provisional name may well have escaped his memory in the midst of the perils and fatigues of his arduous life.

There is certainly no evidence in this Journal that Michaux had ever seen the *Magnolia cordata* of his flora at the time this winter journey to the Blue Ridge was undertaken. No mention is made of the discovery of such a plant during his journey from the coast to the head waters of the Tennessee in the summer of 1787, when it is probable his first visit to the southern mountains was made. Michaux had landed in America as early as November of 1785. The first part of his journal is lost, however, and it is impossible of course to speak with any certainty of his movements during the first eighteen months of his stay in the United States. He had become perfectly familiar, however, as is shown by his journal, with the northern trees prior to his southern mountain journey of 1787, and as under date of January 14, 1787, he speaks of seeing, for the first time in America, *M. acuminata*, one of the common and most conspicuous trees of the southern mountain forests, it appears probable that his early explorations were confined to the sea-board and to the northern States. If this conclusion is correct, it would prove that Michaux was not in pursuit of *M. cordata*, for he would hardly have gone to the mountains in December to search for a tree the existence of which even was unknown to him. On the other hand, had he previously discovered his *M. cordata* and become familiar with its appearance, he would not have undertaken, keen observer as he was, to distinguish it in winter without foliage from *M. acuminata*, one of the common trees of the region, although he would have had no difficulty at any season of the year in distinguishing the bark and bud scales of *M. auriculata*, the tree it must appear evident he was in pursuit of.

It has been suggested that the spot described by Michaux as the "Tête du Keivi" might have been the junction of two rapid mountain torrents, the White Water and the Devil's Fork, which drain the eastern slope of the mountains between the Tugalo and the Keowee, unite, and then join the Keowee. It is more probable however, that the spot described as the head of the Keowee is the junction of the Toxaway and Horse Pasture Rivers, several miles above the mouth of the White Water and close to the North Carolina boundary, although within the limits of the State of South Carolina. They are swift rivers flowing through beds cut deep in the rock, broken by innumerable rapids, and full of logs and bowlders; in each about six miles from its mouth is a noble fall, or rather a series of cascades of great height and beauty. It was near one of these falls probably that Michaux wished to camp on the even-

ing of the 9th of December, and the evidence favors the belief that it was the falls of the Toxaway. The principal Indian trail, leading from the low country to the Cherokee hunting ground on Hogback at the head of the Tuckasegee River, passes by the mouth of the Toxaway to the falls of that river, and then up through the deep ravine north of the Hogback Mountain separating it from Tigertail. Michaux, guided by his Cherokee and anxious to reach the highest mountain in the region, would naturally have followed the more beaten Toxaway trail which leads directly up Hogback, the highest mountain in this neighborhood, rather than by the Horse Pasture to Chimney Top and the less elevated mountains which surround Casher's Valley. He probably camped that night in the shelter of the deep ravine north of Tigertail, where he would have found no pine wood for the fire, and which to-day is covered with a dense forest of deciduous trees. On the 10th, had he ascended the mountains from this camping place, he might have reached the spot where the waters of the Savannah and Tennessee spring from the opposite sides of a narrow ridge. He would have found the mountain forests abounding with *Magnolia auriculata* and *M. acuminata*, and he would have been obliged to cross a great thicket of *Rhododendrons*, the only one, it is said, three miles wide in all this part of the country. It is to-day the greatest bear ground in all the Carolina mountains, and according to tradition one of the most famous of the Cherokee hunting resorts. A chain of high mountains stretching from west to east may be seen from Hogback. It is now called the Balsam Range.

The distance from the summit of Hogback to the head of the Keowee is not more than fifteen miles by the Indian trail. Michaux might therefore have made the ascent from his camp under Tigertail, gathered his Magnolia, and returned to the junction of the two rivers on the evening of the second day. He could hardly have done it in less time at that season of the year, especially if he penetrated far into the Rhododendron thicket.

A little plain less than a hundred acres in extent, now converted into a corn field and dotted with the homes of a few poor families, marks the junction of the Toxaway and the Horse Pasture. The mountains which are "exposées au sud," that is, which face the left bank of the Keowee below the junction of its two mountain branches, are still covered with *M. auriculata*. From the opposite shore at the foot of the mountains which face the north, fifty paces below the junction, the Cherokee hunting trail, as smooth and hard to-day under the tireless steps of the moon-shiners as it was ninety-eight years ago when Michaux saw it, leaves the river, crosses the little

brook and stretches up to the mountains; and here with *Epigea repens* may still be found Michaux's little "*arbuste*" with its "*feuilles denticulées*," the *Shortia* of Torrey and Gray.*

There is no mention in Michaux's Journal of his discovery of the *Magnolia cordata* of his Flora, and no satisfactory record exists that any American botanist has ever collected in a wild state this plant as it is known in cultivation. The younger Michaux in his Sylva says:—"the banks of the Savannah in upper Georgia and those of the stream which traverses the back parts of South Carolina are the place where my father and myself particularly observed this tree." A careful examination made by me on this region and extending over two years, has not resulted in the discovery of *M. cordata*, nor does this tree now grow on the Savannah River about Augusta, where the younger Michaux says that he found it also.

The *Magnolia cordata*, as known in gardens, differs from *M. acuminata* in its thicker branchlets, its less pyramidal habit, and in its generally broader leaves, sometimes, though rarely, sub-cordate at the base, darker green above and more densely pubescent beneath. These appear earlier in the spring and remain upon the trees somewhat later in the autumn. The flowers are often less than half the size of those of *M. acuminata* and are bright yellow instead of pale yellow or green in color. The two trees growing side by side in gardens certainly look distinct; but at different points in the Blue Ridge in North and South Carolina and Georgia and on the mountains of North Alabama, individual Magnolias grow with leaves and flowers intermediate in shape and color between those of *M. acuminata* and the *M. cordata* of gardens, which indicate the close connection between these two species. The specimens collected by Dr. Chas. Mohr in Winston County, Alabama, are nearly identical with the cultivated *M. cordata*, while other specimens

* The botanical readers of this Journal are familiar with the interesting history of this plant In 1839 Dr. Asa Gray found among the undescribed plants of the Michaux Herbarium in the Museum d'Histoire Naturelle in Paris, a single specimen, in fruit only, of a *Pyrola*-like plant collected in the high mountains of Carolina, and which he characterized as the type of the new genus which now commemorates the botanical labors of Dr. Chas. W. Short of Kentucky. A second species of *Shortia* discovered afterwards in Japan confirmed the characters and validity of the genus; but for many years all efforts to rediscover Michaux's plant, although diligently and widely sought by every botanical traveler in the Carolina mountains, failed. In May, 1877, however, *Shortia* was unexpectedly discovered near Marion, North Carolina, at a considerable distance from the high mountains, by G. M. Hyams; so that this second rediscovery is principally interesting in the light it throws upon the route taken by Michaux in his winter journey. There can be no reasonable doubt that *Shortia* was the "*Arbuste*" with "*f. denticulées*" of the Diary, although the term "*Arbuste*" is misleading. *Shortia* is not a shrub, of course, but an herb with stoloniferous stems. The plants gathered by Michaux "in great quantities" probably all perished before reaching France or could not be made to adapt themselves to cultivation. At any rate, there is nothing to indicate that such a plant was ever cultivated in the Paris garden.

from these intermediate forms can only be distinguished from the typical *M. acuminata* by their occasional sub-cordate leaves and smaller flowers. The facts, then, in the case are these. No botanist during the present century has ever discovered in a wild state a tree exactly like the *M. cordata* of gardens, which is now only known by trees propagated and possibly changed by cultivation from the plant or plants introduced into France by Michaux. Forms intermediate in character between *M. acuminata* and *M. cordata* are common in a wild state in the region often visited by Michaux, and where his son says that *M. cordata* was discovered by his father and himself. It is not improbable, therefore, that *M. cordata* may have been founded by Richard, the author of Michaux's Flora, on a specimen from one of these doubtful trees which Michaux himself had not distinguished in the field as a distinct species. But whatever may have been the origin of the species described in Michaux's Flora, these intermediate forms between the two species, which have been discovered of late years, seem to make it necessary to consider Michaux's *M. cordata*, as known in gardens, to be a rare and local variety of *M. acuminata*.*

[Since this article was placed in the printer's hands, Professor Sargent has received a letter from a correspondent resident in the region, reporting the discovery of the *Shortia* at another station in the vicinity, where there were "rods covered with it." We may now hope that the continued survival of this notable member of our flora is assured. The interest of botanists in this rediscovery of the original habitat by Professor Sargent, and its extension by his correspondent, is of the highest.

Let me add that "les sauvages" who told Michaux that the leaves are pleasant-tasted and aromatic when crushed, must have had reference to *Gaultheria procumbens* and not to the *Shortia*, the foliage of which is slightly mucilaginous and odorless.—A. GRAY.]

ART. LV.—*Note on the Age of the Swedish Paradoxides Beds;* by S. W. FORD.

IT has been customary to look upon the Swedish Paradoxides beds as representing, in part, the oldest known portion of the Primordial zone. M. Linnarsson, in comparing these beds with those of the Menevian and Harlech groups of Great Britain, states that the latter "correspond to the Swedish Paradoxides beds and, in part, to the sandstones underlying the Paradoxides

* *Magnolia acuminata* var. *cordata.*

M. foliis lato-ovalis basi subcordatis vel ovalibus acuminatis subtus pubescentibus vel subtomentosis; floribus flavis.

A small tree sometimes 60 feet in height, the leaves darker green and more persistent than those of the species with which it is often associated on dry ridges and mountain slopes. Northern Alabama. (C. Mohr) Blue Ridge, North and South Carolina (Sargent) and common in gardens.

beds."* More recently Mr. G. F. Matthew, in announcing the interesting discovery of the Swedish species, *Paradoxides Kjerulfi* Linnarsson (*Olenellus* (?) *Kjerulfi* Brögger) in America,† states that this species, if "present in America at a horizon corresponding to that at which it occurs in Europe, should show itself in band *b* of Division 1" of the New Brunswick measures, instead of in strata which are regarded as the equivalents of the Menevian group of the British geologists; from which it would appear that he also considers the Swedish Paradoxides beds as in some measure equivalent to the Harlech or Solva formation. According to Mr. Matthew, *P. Kjerulfi* has been found both in Newfoundland and in the Kennebecasis Basin of New Brunswick; and is associated in the latter locality with a number of species found in the St. John Basin, which are similar to and in some cases identical with those of the Menevian group of Wales. The beds in which it occurs in Newfoundland, were set down as Menevian by Billings, so long ago as 1872.

The several subdivisions recognized in the Swedish Paradoxides beds, and their order of succession, were given by M. Linnarsson in 1876 as follows:

(6.) Strata with *Agnostus lævigatus.*
(5.) Strata with *Paradoxides Forchhammeri.*
(4.) Strata with *Paradoxides ölandicus.*
(3.) Strata with *Paradoxides Davidis.*
(2.) Strata with *Paradoxides Tessini.*
(1.) Strata with *Paradoxides Kjerulfi.*

With respect to the above succession, M. Linnarsson admits that the position of the fourth subdivision, or that of the "Strata with *Paradoxides ölandicus*," is doubtful. Division 2 holds, in addition to *Paradoxides Tessini*, the British species *P. Hicksi* Salter, which is followed in the next superior division, as in the Welsh measures, by the great *P. Davidis*. The position of *P. Hicksi* in the British beds is in the lower portion of the Menevian group, and that of *P. Davidis* in the middle; and this, it will be seen, is almost exactly their position in the Swedish Paradoxides beds. Salter has pointed out the fact that *P. Hicksi* is a good deal like an *Anopolenus*. The bulk of the Swedish fauna appears to be concentrated in Div. 5, or in that of the "Strata with *Paradoxides Forchhammeri*," which had yielded, up to 1876, about forty species, representing the genera *Paradoxides*, *Agraulos*, *Anomocare*, *Liostracus*, *Dolichometopus*, *Conocoryphe*, *Solenopleura*, *Elyx*, *Harpides?*, *Aneuacanthus*,

* "On the Brachiopoda of the Paradoxides beds of Sweden," p. 27, 1876. (Bihang till K. Svenska Vet. Akad. Handlingar. Band iii, No. 12).
† This Journal, III, xxxi, p. 472.

Corynexochus, *Agnostus*, *Hyolithes*, *Orthis*, *Lingulella*, *Obolus?*, *Obolella?*, *Acrotreta*, *Acrothele*, *Kutorgina* and *Iphidea*. Of these, two, *Orthis Hicksi* and *Obolella? sagittalis*, are well-known Welsh Menevian species. A considerable number of the genera of the Swedish measures are wanting in the British Menevian beds, and *vice versa;* but this, I think, is no more than might be reasonably expected in the case of so widely separated exposures of the same formation.

In view of the above facts, I think we may assume with a very considerable degree of confidence, that the Swedish Paradoxides beds, or at any rate those above the Division characterized by *Paradoxides Kjerulfi*, are of the age of the Menevian group; and the question arises whether there is anything in the aspect or structure of this species to prevent the division in which it occurs from being also regarded as Menevian. In an earlier paper (this Journal for October, 1881), I have discussed at some length the structure and relations of this species; and I see no good reason at present to modify the opinions concerning its affinities therein expressed. The view I took at that time was, that *P. Kjerulfi*, although confessedly an aberrant form, should nevertheless be regarded as a *Paradoxides*. There are a number of strong points of resemblance between this species and *P. ölandicus* Sjögren,* judging from the figures which I have seen of these forms; and that the latter is a true *Paradoxides* I think admits of no question. The Swedish *Paradoxides*, like those of the typical Menevian beds, and unlike those of Bohemia, are all, so far as determined, of the *Brachypleural* type; i. e., have all of their anterior pleura of the same relative length in the fully developed or adult forms; but whether this is true of the particular species *P. Kjerulfi* is not at present known. I have elsewhere presented reasons for believing that the *Brachypleural* species of the genus *Paradoxides* are more recent than the *Macropleural*, based upon facts furnished by the Life History of *Olenellus asaphoides*. Mr. Matthew, in speaking of the American specimens of *P. Kjerulfi*, says that the glabella is not enlarged in front as in the true *Paradoxides;* but the figures given by M. Linnarsson show that in the Swedish specimens, or at any rate, in those illustrated, it is. He further says that the position of this species (which he calls, upon the authority of Professor Brögger, *Olenellus* (?) *Kjerulfi*) in Europe, "is beneath that of the beds carrying *Paradoxides;*" but until it is proved that *P. Kjerulfi* is not a *Paradoxides*, it seems the better course to say this its position in Europe is at the *base* of the Swedish beds carrying *Paradoxides*.

* Geol. Fören. Förhandl., Bd. i, p. 72, t. 5, fig. 1, 1872.

In any event, the facts (1) that the position of *P. Kjerulfi* in the Swedish Primordial is directly below the zone carrying the British *P. Hicksi;* (2) that it is clearly allied to *P. ölandicus*,—a *Brachypleural* species and an undoubted *Paradoxides;* and, (3) that it is a Menevian species in America; all appear to me to indicate that it is a Menevian species in Europe also, and that the strata there affording it may be regarded as constituting a legitimate portion of the Swedish *Paradoxides* measures.

Schodack Landing, N. Y., Sept. 25th, 1886.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Determination of Fusing points.*—Roth has suggested a new form of apparatus for determining fusing points. It consists of a bulb 65^{mm} in diameter, having a neck 200^{mm} long and 28^{mm} wide, within which is a straight tube closed at bottom, 15^{mm} wide, sealed to the outer tube above and passing down to within 17^{mm} of the bottom of the bulb. The outer tube has a lateral tubulure closed by a perforated stopper, so that communication with the outer air may be opened or cut off at will. The flask is filled to two-thirds its height with sulphuric acid. To use the apparatus the substance is placed in the inner tube and the temperature of the acid is gradually raised until fusion takes place, the temperature being carefully noted by an accurate thermometer placed within this inner tube. A comparison by the author shows that the correction required when the thermometer is placed in the sulphuric acid, brings the corrected fusing point to the value directly observed by the method now described, within the limits of the errors of observation. Thus the fusing point of benzoic acid with the thermometer in the acid, is 121·5°, and corrected 123·3°; while the temperature observed directly in the inner tube was 123°. Nicotinic acid fused at 228°, or corrected at 234·6°; while the temperature observed in the tube was 235°.—*Ber. Berl. Chem. Ges.*, xix, 1970–1973, July, 1886.

G. F. B.

2. *On the Determination of Molecular Weights of Substances by means of the Freezing points of their Solutions.*—In order to ascertain how far the method proposed by Raoult for fixing molecular weights by means of the depression of the freezing point,* was applicable to organic compounds, Paterno and Nasini have submitted to examination (*a*) several pairs of polymers, such as aldehyde and paraldehyde, acetonitrile and cyanmethin, cyanamide and dicyanamide etc.; and (*b*) certain bodies whose molecular weight is not as yet fixed, such as lapachoic acid and lapachon,

*See this Journal, xxix, 399, May, 1885.

picrotoxine and picrotoxide hydrate, santonin and santonid. Raoult's method was strictly followed. The quotient of the depression of the freezing point in degrees by the concentration of the solution, i. e., the weight of substance in 100 c.c. of it, gives the depression coefficient, or the depression given by one gram of the substance in 100 c.c. This, multiplied by the molecular weight, gives the molecular depression. Thus, for aldehyde C_2H_4O in water the depression-coefficient for various strengths of solution, was 0·4107, 0·4274, 0·4279 and 0·4369; the corresponding molecular depressions being 18·07, 18·81, 18·83 and 19·22. For paraldehyde $(C_2H_4O)_3$, the depression-coefficient was 0·1458, 0·1513, and the molecular depression 19·24 and 19·97; practically the same. Cyanamide CN_2H_2 has a molecular depression of 16·28, dicyanamide $(CN_2H_2)_2$ of 15·54. Acetonitrile $CH_3.CN$ afforded a molecular depression of 17·78, 17·28, and 18·61 in three experiments; but cyanmethin $(CH_3.CN)_3$ varied its depression-coefficient from 0·0786 to 0·0461 according to the concentration of the solution; giving a molecular depression varying from 5·67 to 9·67. This would suggest a molecule two or three times as large, either $(CH_3.CN)_6$ or $(CH_3.CN)_9$; values not in accordance with the vapor density or chemical behavior of this substance. Lapachoic acid $C_{15}H_{14}O_3$ in benzene gave a molecular depression of 46·37; and lapachon, with the same formula, one of 43·10. Picrotoxine $C_{12}H_{14}O_5$, in acetic acid, gave 43·15, and 43·22; while picrotoxide hydrate $C_{15}H_{18}O_7$ gave 44·98 and 40·98 in two experiments. In general the authors consider Raoult's law to be exact, and regard it of great value in fixing molecular weights. Their experiments are to be continued. —*Ber. Berl. Chem. Ges.*, xix, 2527–2530, Oct. 1886. G. F. B.

3. *On the Magnetic Rotation of mixtures of the Fatty Acids, of Alcohol and of Sulphuric Acid, with Water.*—PERKIN has continued his researches upon the relation between the chemical constitution of substances and their power of rotating the plane of polarization when under magnetic influence,* and has now given the results of his examination of the rotation produced in mixtures of water with the fatty acids, with alcohol and with sulphuric acid. He calls the specific rotation of a substance the ratio of its observed rotation to that of water under the same conditions. By multiplying the specific rotation thus obtained by the ratio of the molecular weights of the substance and of water, and then dividing by the density of the substance, the molecular rotation of the given substance is ascertained. In a previous memoir, he had shown that the molecular rotation of water, assumed as unity, is not the same as the sum of the values of oxygen and two of hydrogen as deduced from the molecular rotation of other compounds. Thus hydrogen is found to be 0·254, while oxygen in hydroxyl varies from 0·194 in ordinary alcohols to 0·137 in monobasic acids, and is 0·261 in carbonyl. Taking the lowest numbers, $H_2+O=0·645$, and the highest, it is 0·769, instead of one. This difference between the molecular

* See J. Chem. Soc., xlv, 421–580, Sept., 1884.

rotation of water in the free and in the combined form suggested the possibility of determining by means of the magnetic rotation whether the water in hydrated compounds existed as such or whether it was present in actual combination. If the former, the numbers obtained should represent the value for the compound plus that of the water; if the latter, lower values would be obtained. Thus if a molecule of formic acid were mixed with a molecule of water we might have either $HCOOH+H_2O$, or $HC(HO)_3$; the molecular rotation being in the first case 2·671 and in the second not over 2·340. Experiment gave 2·666. The molecular rotation of acetic acid, under the same conditions, was 3·554, of propionic acid 4·512, and of ethyl alcohol, 3·787; the calculated values on the supposition that the water exists as such in them, being 3·525, 4·462 and 3·780 respectively. "The foregoing results," the author says, "are further evidence of the fact that although thermal changes and alterations of density result from chemical action, yet that they themselves are not evidence of chemical action." With sulphuric acid, whose molecular rotation was 2·315, it was found that the addition of one molecule of water brought this value to 3·188, two molecules to 4·113, and three to 5·064; the calculated values of course being 3·315, 4·315 and 5·315. There is hence an increase of rotation in the first case of 0·873, in the second of 0·925 and in the third of 0·951. These numbers indicate that the largest amount of combination takes place when the first molecule is added and therefore it seems probable that only one chemical compound results from the action of water on sulphuric acid, namely, $(HO)_4SO$. With regard to water of crystallization, the author calls attention to the want of consistency as to the presence or absence of such water in the simple salts of metals belonging to the same class; such for example as the salts of silver, potassium and sodium. These inconsistencies are so great that it is impossible in his opinion to believe that water of crystallization has any relationship to chemical combination. It appears to him that the relationship is a purely physical one, its presence with the compound being necessary for the building up of the crystalline form which can most readily be produced. "If a salt by itself," he says, "can produce the most easily formed crystalline structure, it will naturally do so and be anhydrous; but if on the other hand it cannot do so, it will associate itself with that number of molecules of water with which it can most readily produce the crystalline form."—*J. Chem. Soc.*, xlix, 777–790, October, 1886. G. F. B.

4. *On the Behavior of Alkali-earths and their Hydrates to dry Carbon dioxide.*—SCHEIBLER has undertaken a series of experiments in order to ascertain the action which dry carbon dioxide exerts upon the alkali-earths and their hydrates. The following are his conclusions: 1st. Perfectly dry carbon dioxide does not combine either with the caustic anhydrous oxides of the earth-metals or with their mono-hydrates; or with hydrated ba-

rium monohydrate, $Ba(OH)_2+1$ aq. 2d. When the hydrates $Ca(OH)_2$, $Sr(OH)_2$ and $Ba(OH)_2+1$ aq. contain more water than corresponds to these formulas, this excess of water is set free at temperatures above 100° C. solely by the action of the heat, and is then carried away by the current of carbon dioxide gas precisely as it would be in a similar current of an indifferent gas. But now the carbon dioxide becomes by this means moist and reacts upon the monohydrate to form carbonate, the amount of which is proportional to the quantity of water set free. Complete conversion of the hydrate into carbonate does not take place even when the water set free reaches its maximum, as in the case of the crystallized hydrate $Sr(OH)_2+8$ aq. 3d. The use of a current of dry carbon dioxide for the purpose of driving out by the aid of heat the combined water of the alkali-earths and the conversion of these earths completely into carbonates, is not satisfactory as an analytical method.—*Ber. Berl. Chem. Ges.*, xix, 1973–1982, July, 1886. G. F. B.

5. *On the Synthesis of active Conine.*—Ladenburg has repeated his experiments upon the synthesis of conine upon a larger scale and has confirmed his former results. The α-allylpyridine was prepared by heating the carefully purified α-picoline in sealed tubes with paraldehyde to 250°–260° for ten hours. From 1 kilo crude α-picoline, by repeating the process, 380 grams pure α-picoline and 45 grams allylpyridine were obtained. Its reduction to α-propylpiperidine was effected by means of sodium, and yielded nearly the theoretical quantity. The hydrochlorate crystallized in white silky needles permanent in the air and fusing at 203°–205. The base itself shows the closest similarity to conine, agreeing with it in odor and in its behavior to water, in its specific gravity, 0·8626 at 0°, and in the properties of its salts, especially the double chlorides of gold and of platinum. To still further establish the identity of these bodies, the author converted the α-propylpiperidine into conyrine and observed identically the same fluorescence in the crude product though the pure substance was free from it. The platinum salt had the same fusing point and the same crystalline form. The physiological action of α-propylpiperidine is identical with that of conine as proved by Falck. The author believes that he has established the complete identity of these two substances, and therefore has prepared for the first time by pure synthesis a vegetable alkaloid. — *Ber. Berl. Chem. Ges.*, xix, 2578- 2583, October, 1886. G. F. B.

6. *On the Identity of Cadaverine with Pentamethylenediamine.* —Ladenburg has succeeded in identifying the base which Brieger discovered a year or more ago in the dead body and which he called cadaverine, with the base recently discovered by himself and called pentamethylenediamine. The two bases have the same boiling point, the same solubility and the same odor. The mercury double salt, however, obtained from pentamethylenediamine hydrochlorate by mixing its solution with one of mercuric chloride, forms crystals having the formula $C_5H_{14}N_2(HCl)_2$

$(HgCl_2)_3$; while the cadaverine salt seems to have four mercuric chloride molecules. Moreover the author has converted cadaverine into piperidine and observed its identity with that from the other base. Its chlorhydrate fused at 237°, and it formed a beautifully crystallized double platinum salt fusing at 194°–195°. —*Ber. Berl. Chem. Ges.*, xix, 2584–2586, October, 1886. G. F. B.

7. *On a method of obtaining Hydrochloric acid absolutely free from Arsenic.*—The large quantity of hydrochloric acid which is required to destroy the organic matter by the process of Fresenius and Babo in cases of poisoning, renders it necessary to purify this acid from arsenic with the greatest care. Otto, after giving the various methods proposed for doing this, calls attention to one which he has recently adopted. It was suggested by observing that the crude acid of commerce, after treatment with hydrogen sulphide and fractional distillation, contained not a trace of arsenic. Hence it appeared that the impurities present in the crude acid enabled the hydrogen sulphide to precipitate the arsenic completely. Experiment confirmed this conjecture and proved that the last minute trace of arsenic present in the purest hydrochloric acid of commerce is precipitated as arsenous sulphide in the presence of other impurities; and further that by adding to the acid before precipitation some substance precipitable by hydrogen sulphide, this last trace of arsenic can be absolutely removed. To test this question thoroughly, seven portions of hydrochloric acid, of two liters each, of sp. gr. 1·12 (one portion of which had been shown by Marsh's test to give a mirror corresponding to about one-tenth of a milligram of arsenous oxide, were treated as follows: (*a*) with 5 grams of a ten-per cent solution of ferric chloride, (*b*) with 2 grams of potassium dichromate, (*c*) with 2 grams mercuric chloride, (*d*) with 1 gram cadmium sulphate, (*e*) with 1 gram copper sulphate, (*f*) with 30 grams of a saturated solution of sulphurous acid, and (*g*) with 30 grams of a half-per cent solution of chlorine. These portions of acid were then saturated with hydrogen sulphide, and allowed to stand for some time. They were then filtered and the filtrate tested for arsenic without giving the slightest trace of a mirror. The precipitates from portions *a*, *b*, *f*, and *g* showed the presence of arsenic. Indeed even the presence of arsenous oxide itself determines the absolute precipitation of traces of arsenic from the acid. Two liters of the same acid as above were treated with 0·2 gram As_2O_3 and then with hydrogen sulphide. The filtrate was free from arsenic. To obtain pure hydrochloric acid the author advises that the crude acid of commerce be diluted to the sp. gr. of 1·12, treated with washed hydrogen sulphide to saturation, allowed to stand for 24 hours at 30°–40°, again treated with H_2S, and allowed to stand, the clear liquid decanted and carefully distilled, reserving the middle portions. In five liters of acid thus purified the author could detect no trace of arsenic by Marsh's test.—*Ber. Berl. Chem. Ges.*, xix, 1903–1919, July, 1886. G. F. B.

8. *Fluorescence.*—M. Lecoq de Boisbaudran calls attention to the fluorescence manifested by various salts of manganese under the influence of electrical discharges in vacuum tubes. The fluorescence of certain of these compounds provides an extraordinary sensitive reaction to detect the presence of manganese in substances which give no trace of it by ordinary reactions. Sulphate of lime and carbonate of lime mixed with very small proportions of manganese render, after strong calcination, magnificent fluorescence.—*Comptes Rendus*, No. 10, Sept. 6, 1886. J. T.

9. *Instantaneous Photography.*—M Marey has devised an arrangement by means of which the light coming from the background against which the quickly moving objects are photographed can be cut off. This light has hitherto affected the sensitive plates and often injured the clearness of the impression. By means of certain precautions, M. Marey has been able to reduce the time of pose, for each image, to ·002 of a second and hopes to still further reduce it. The new photographs show an extraordinary clearness of impression under the shortening of the time of exposure. The pivoting of the wings of birds upon their longitudinal axis is clearly shown and also other and various peculiarities of their flight. The author expresses his obligation to certain suggestions of Chevreul.—*Comptes Rendus*, No. 13, Sept. 27, 1886. J. T.

10. *A Potential strengthener for measurements.*—All electrometers hitherto constructed do not equal galvanometers in sensitiveness and accuracy of indication. Hallwachs has invented a species of induction machine which can be used in connection with a quadrant electrometer. His paper gives a careful description of the apparatus and a discussion of the errors to which it is subject. This apparatus consists of a half cylinder condenser, of which the collector can be set in rotation and thus be placed opposite, and in turn removed from the condensed plate. The instrument gives for one Daniell cell with a scale distance of 3 meters 300 scale divisions on changing the quadrants of the electrometer.—*Ann. der Physik und Chemie*, No. 10, 1886, pp. 300–313. J. T.

11. *Compressibility and Surface Tension of Liquids.*—W. C. Röntgen and J. Schneider are occupied upon a research in this subject with various chemically well defined substances. Their present paper is a preliminary one. Among its results, however, is the following: If the fluids examined are arranged in the order of compressibility, the following order is observed: J, No_3, Br, Cl, OH, SO_4, CO_3, H, Am, Li, K, Na. The authors discuss the order of compressibility of various salts of the above, for instance, $LiNO_3$, $NaNO_3$, etc., and find that the compressibility of a salt solution is smaller than the arithmetic mean of the compressibility of an equally concentrated solution of salt and of base.—*Ann. der Physik und Chemie*, No. 10, 1886, pp. 165–213. J. T.

12. *Observations on pure Ice and Snow.*—Some experiments have been made by T. Andrews in regard to the relative conduc-

tivity of ice and snow, the dilatation of pure ice, and its relative penetrability at various temperatures. In experimenting in regard to the first point a mass of water about 2 feet square and 1 foot high was converted into ice by a freezing mixture and a uniform temperature of 0° F. obtained. In place of the freezing mixture fresh snow was then supplied and the gradual increase of temperture noted by a series of thermometers until the whole mass was at 32° F. This required 73½ hours. The experiment was then repeated with pure snow lightly pressed together; 165½ hours were required to bring it up from 0° F. to 32° F. The relative conductivities obtained are expressed in a diagram, the conclusion being that the conductivity of the ice was about 122 per cent greater than the snow under the conditions of the experiment.

The dilatation of ice was measured between −35° F. and +32° F. The linear coefficients obtained are as follows:

Linear coefficient for 1° between			+16°	F. and	+32°	F. = 0·000040876.
"	"	"	0	"	+16	" = 0·000028042.
"	"	"	−21	"	0	" = 0·000020484.
"	"	"	−30	"	−21	" = 0·000019744.

The hardness of ice at different temperatures between −35° F. and +32° F. was measured by the relative depths to which a blunt-pointed steel rod with a weight of 181½ lbs. on its top penetrated. It was found that between −35° F. and +10° or 20° F. the ice was nearly impenetrable, the depth of penetration being only ¼ inch at 10° and ⅔ inch at 20°; after which the power of resistance decreased rapidly with the temperature.—*Proc. Roy. Soc.*, xl, 544, 1886.

II. Geology and Natural History.

1. *On the gaseous constituents of Meteorites.*—Ansdell and Dewar have continued the work begun by Graham and carried further by Mallet, Wright and others in regard to the gases occluded in meteorites. The results of the analyses of the gases in three meteorites are given in the following table, with which those obtained from a piece of fresh pumice are compared:

	Sp. gr.	Occluded gases in vols. of the meteorite.	Percentage composition. CO_2	CO	H	CH_4	N
Dhurmsala	3·175	2·51	63·15	1·31	28·48	3·9	1·31
Pultusk	3·718	3·54	66·12	5·40	18·14	7·65	2·69
Mōcs	3·67	1·94	64·50	3·90	22·94	4·41	3·67
Pumice-stone,	2·50	0·55	39·50	18·50	25·4	...	16·60

In order to test directly the absorptive power of one of the porous stony meteorites, a sample of the powdered Dhurmsala stone, from which the gases had been already removed, was left in moist air under a bell glass for a longer or shorter period. The results are given for the different periods in the following table; the gases were drawn off at a low red heat after the time given in each case:

	Occluded gas in vols. of the meteorite.	CO_2	CO	H	N
After 24 hours	0·61	54·0	--	42·4	3·6
After 6 days more	2·47	47·0	5·0	47·0	1·0
After 8 days more	0·63	96·1	2·0	1·5	--

A nodule of graphite from the Toluca iron was next examined, and for comparison several terrestrial graphites and one artificial specimen (obtained from the action of oxidizing agents on the cyanogen compounds present in crude caustic soda) were tested in the same manner. A specimen of semi-decomposed gneiss from Canada containing disseminated graphite, and one of feldspar were also taken. The results were as follows:

	Sp. gr.	Occluded gases in vols. of the graphite.	CO_2	CO	H	CH_4	N
Celestial graphite,	2·26	7·25	91·81	----	2·50	5·40	0·1
Borrowdale "	2·86	2·60	36·40	7·77	22·2	26·11	6·66
Siberian "	2·05	2·55	57·41	6·16	10·25	20·83	4·16
Ceylon "	2·25	0·22	66·60	14·80	7·40	3·70	4·50
Unknown "	1·64	7·26	50·79	3·16	2·50	39·53	3·49
Artificial "	---	53·13	45·42	39·88	8·31	4·43	2·00
Gneiss	2·45	5·32	82·38	2·38	13·61	0·47	1·20
Feldspar	2·59	1·27	94·72	0·81	2·21	0·61	1·40

An examination was also made of the carbonaceous Orgueil meteorite with the following results:

	Sp. gr.	Occluded gases in vols. of the meteorite.	Percentage composition. CO_2	CO	CH_4	N	SO_2
Orgueil meteorite	2·567	57·87	12·77	1·96	1·50	0·56	83·00

Deducting the sulphur dioxide which has been formed from the decomposition of the sulphate of iron, the meteorite is found to yield 9·8 times its volume of gas having the composition:

CO_2	CO	CH_4	N
76·05	11·67	8·93	3·33

The organic matter, which is the feature of the meteorite, contains according to Clöez: C 63·45, H 5·98, O 30·57, or corresponding nearly to the composition of terrestrial humus.—*Proc. Roy. Soc.*, xl, 549.

2. *Recent discovery of Emeralds and Hiddenite in North Carolina;* by W. E. HIDDEN (communicated).—On the second and ninth of last August, two crystal pockets were uncovered at the Emerald and Hiddenite mine in Sharpe's township, Alexander County, North Carolina, that yielded a few very remarkable crystals of emerald and of hiddenite. The emerald pocket extended in a nearly vertical direction for twenty feet and was about one foot in diameter and four feet in its extreme lateral extent. The associated minerals were quartz crystals (from one ounce to twenty pounds weight and some that were fluid-bearing), green muscovite (fuchsite?), rutile, dolomite and minute crystals of monazite. The emeralds found were nine in number and as

regards color, perfection of form, and crystallographic interest, have not been surpassed at this locality. The largest emerald weighed nearly nine ounces and was three inches long by one and three-quarters in diameter. All the crystals possessed the same relative proportion of thickness to length (2 : 3), and were alike in being doubly terminated. The plane of attachment to the walls seemed to be relatively the same on all. Hair-like needles of some unidentified mineral penetrated the emerald crystals more or less; which feature pertains also to certain rare crystals of green spodumene from the same locality. The occurring planes were principally the ordinary prism *I* and the basal pinacoid *O*, though 2–2, 1 and other pyramids were noticed. The usual characteristic feature of vertical striation was hardly observable. The polish of the basal pinacoids was remarkably perfect, as was shown by two of the crystals being placed end to end supporting each other when held vertically. One of the crystals was especially remarkable from having implanted upon a prismatic face, a very brilliant crystal (2×10 mm.) of rutile, of perfect form, which seemed to be in exact parallel position axially with the emerald. A very low obtuse pyramid was finely developed (2×6 mm.) on two of the crystals and upon being measured with a reflective-goniometer by Mr. Edward S. Dana has been proved to be new to the species. Its symbol is $\frac{1}{6}$–2 ($1\cdot1\cdot\bar{2}\cdot12$.) Its angle on *O* is 4° 27′ to 4° 49′ measured, 4° 44½′ calculated, also $\frac{1}{6}$–2 ∧ $\frac{1}{6}$–2, adj. = 4° 24′ measured and 4° 44′ calc. This new plane lies in the zone *i*–2 : 2–2 : *O*. It was striated horizontally.

The discovery above described was followed a week later by the finding of hiddenite (emerald-spodumene) crystals of fine color and in one instance of unprecedented size. They were found only about three rods west of the point where the emeralds were found. About ten ounces of fine green crystals were found in the pocket, which was but four feet in extent, and otherwise a very narrow seam in the partly disintegrated gneissic rock. The accompanying minerals were the same as in the emerald pocket already described; no beryls or emeralds were found with the spodumene, as is the general rule at this locality. The largest crystal weighed ½ an ounce and was two and three-quarter inches long and three-sixteenths by nine-sixteenths of an inch through the clino- and ortho-axes. It is a twin, with a projecting edge at the termination. The color at the terminal *end*, for three-quarters of an inch, was a fine emerald-green, while the balance of the crystal was of a chrysolite green shade.

3. *Mineral Physiology and Physiography*, a second series of chemical and geological essays, with a general introduction, by T. Sterry Hunt. 710 pp. 8vo. Boston, 1886 (S. E. Cassino).—The essays here collected include Dr. Hunt's more recent contributions to science, namely, "Nature in Thought and Language," "The order of the Natural Sciences," papers on the atmosphere, celestial chemistry, the origin of crystalline rocks.

The decay of crystalline rocks, a "natural system in Mineralogy," history of Pre-Cambrian rocks; on Serpentines, and "the Taconic question in Geology."

4. *Index der Krystallformen der Mineralien*, von VICTOR GOLDSCHMIDT. Band I, Lieferung 2; pp. 289 to 601. Berlin, 1886. (Julius Springer).—The second part of Dr. Goldschmidt's great work—noticed on page 475 of the last volume—completes the first of the three proposed volumes. All the mineral species through E are included here. The whole work is a model of thoroughness and accuracy and in clearness of presentation and beauty of typographical work it leaves nothing to be desired. It is to be hoped that the author's labors will receive the support from mineralogists which they decidedly deserve.

5. BOTANICAL NOTES.—*Lamarck's Herbarium*, which has been for more than half a century the property of the late Professor Rœper and at Rostock—far out of the way—has now, it is stated, been bought for the Jardin des Plantes at Paris, where it will be much more accessible. Probably it is not large, nor at all complete in his types of the species of the earlier volumes of the Dictionary. But so far as it goes it will be more helpful now that it is in its proper place.

The extensive series of drawings and descriptions of Manilla plants, made in the seventeenth century by the Jesuit *Kamel* or *Camellus* (in honor of whom was the genus *Camellia* named), and which Ray refers to as in his possession, had utterly disappeared. From an account recently given by M Paque to the Royal Botanical Society of Belgium, it appears that this work exists, in fine condition, in the library of the Jesuit's College at Louvain; that it belonged to A. L. de Jussieu at his death, was bought by Count de Limminghe at the sale of Jussieu's library in 1858, and presented to the College where it is now preserved. There are 257 botanical plates, containing 556 figures.

Dr. Saint-Lager has issued a new bulletin on *Le Procès de la Nomenclature Botanique et Zoologique* (Paris, Baillière, pp. 54), in which his well known reformatory ideas are reiterated.

Phytobiological Observations, on the Forms of Seedlings and the causes to which they are due, is the subject of the address to the Linnean Society of its retiring President, Sir John Lubbock, at the anniversary meeting in May last, now published, with copius illustrations, as an article in the Journal of that Society, No. 147. It brings to view adaptations rather than causes, in the old fashioned sense of the latter word.

Hooker's *Icones Plantarum*, vol. xvi, part 2, has just been brought out under the auspices of the "Bentham Trustees." It comprises plates 1526 to 1550, inclusive; none of North American plants. But Professor Oliver figures a new chinese genus, *Plagiospermum*, which is thought to be allied to the exceptional genus *Glossopetalon*. The alliance is not obvious, and the new genus has rather a Rosaceous look. A. G.

6. *Absorption of coloring matters by the living protoplasm of vegetable cells.*—The following extract from a recent work on Vegetable Physiology expresses in a few words the generally accepted view relative to the action of dyes on vegetable cells. "It is impossible to stain living protoplasm: it is when protoplasm is dead that coloring matters can penetrate into it." The first part of this statement requires an important qualification.

Passing by certain well known facts relative to the transient tinging of animal protoplasm in certain cases, noted by Heidenhain, Brandt, and Dreser, attention is asked to the recent discovery by Pfefferin (Unters. aus dem botan. Inst. Tübingen, Band ii, iv). Professor Pfeffer shows that when living vegetable cells are placed in *very dilute* solutions of certain coal-tar coloring matters, the protoplasm becomes distinctly colored, and remains tinged for a time. The best results are obtained by placing roots with attached root-hairs, in half a liter of pure water to which is added one ten-thousandth of one per cent of almost any of the so-called methyl colors, such as "methyl-green," "methyl-violet," "methyl-orange :" and such colors as safranin, Bismarck-brown, and the like. Nigrosin, and eosin, and two or three others are not well adapted to the purpose. After a short time, especially if the specimen is shaken in the solution, the protoplasm will be found distinctly tinged. But a few colors, notably methylene-blue, do not color the protoplasm at all, but impart to the cell-sap an intense color. In this case, the dye has passed through the protoplasm without tinging it, into the cell-sap which receives it. G. L. G.

III. Miscellaneous Scientific Intelligence.

1. *The Astronomical Journal.*—It is gratifying that Dr. B. A. Gould has again undertaken the publication of The Astronomical Journal which was discontinued in 1861. A real impulse was given to Astronomy in this country by the first six volumes of the Journal. We may hope for a like effect from the renewal of the publication at this time. The object of the Journal is now, as heretofore, the advancement rather than the diffusion of astronomical knowledge.

The first number of the seventh volume is dated at Boston, Nov. 2, 1886. The price is $5 for twenty-four numbers, which, for the present, may be sent directly to Dr. Gould at Cambridge. It is earnestly hoped that a liberal support will be given to the undertaking.

2. *National Academy of Sciences.*—List of the papers entered to be read before the Academy at the session in Boston, Nov. 9th and 11th, 1886.

S. P. Langley: The Solar-Lunar Spectrum.
E. C. Pickering: Draper Memorial Photographs.
C. H. F. Peters: A Chart of the Stars in the group Præsepe.
C. H. F. Peters: A Catalogue of Stars from positions in various Astronomical Periodicals.
O. T. Sherman: A Catalogue of Bright Lines observed in the atmosphere of β Lyræ.

W. L. ELKIN: On the relative motions of the Pleiades group deduced from measurements made with the Königsberg and Yale College heliometers.
C. A. YOUNG: Some observations with Pritchard's Wedge Photometer.
C. ABBE: The question of Barometer Exposure.
G. W. HILL: On the Construction of New Tables of Saturn.
T. STERRY HUNT: A Basis of Chemistry.
T. STERRY HUNT: Hardness and Chemical Indifference in Solids.
ALPHEUS HYATT: Primitive Forms of Cephalopoda.
ALPHEUS HYATT: A Case of Evolution in the Migration of Forms.
ALPHEUS HYATT: Lituites of the Limestones of Phillipsburg, Canada.
F. W. PUTNAM: Archæological Explorations in the Little Miami Valley, Ohio, conducted by F. W. Putnam and C. L. Metz.
E. D. COPE: On Lemurine Reversion in Human Dentition.
E. D. COPE: On the Columella Auris of the Tailed Batrachia.
EDW'D S. MORSE: Change in Mya since the Pliocene.
A. S. PACKARD: The Cave Fauna of North America, with Remarks on the Anatomy and Origin of Blind Forms.
R. PUMPELLY: On the Relation of the Green Mountain Rocks to the Taconic.
W. M. DAVIS: The Mechanical Origin of the Triassic Monoclinal in the Connecticut Valley.
ALFRED RUSSELL WALLACE: On Wind as a Seed-Carrier in relation to one of the most difficult problems in Geographical Distribution.

3. *Catalogue of the Collection of Minerals of A. Dohrmann.*—Messrs. S. H. and H. Chapman have issued a handsome catalogue of the Dohrmann collection of minerals which is to be sold in Philadelphia about the middle of December. The catalogue contains a description of about 1100 numbered specimens, the majority of them gold or silver. A number of artotype plates give fine representations of some of the more striking specimens.

OBITUARY.

CHARLES WHITTLESEY.—Col. Whittlesey, whose decease is announced on page 412 of this volume, was a graduate of the United States Military Academy at West Point in 1831. His work in Geology began soon after, and in 1837 he was appointed an assistant on the Geological Survey of Ohio, which was then under Mr. W. W. Mather, and given the direction of the topographical department. From 1847 to 1851 inclusive, he was connected with the Government Survey of Lake Superior and the upper Mississippi with reference to mines and minerals; and from 1858 to 1860 he was by request of Prof. James Hall associated with him on the Geological Survey of Wisconsin. In 1848, 1859 and 1864, he made explorations in the mineral regions of Minnesota, and published a report on the same in 1866. Mr. Whittlesey was the author of papers on the drift of Ohio, the terraces of Lake Erie, and various other subjects, and in one of them described a new coal plant of peculiar type, which afterward received (through Dr. Newberry) the generic name of Whittleseya. His latest contribution to this Journal was in the spring of 1885, on the Preglacial Channel of Eagle River. Two of his papers are among the publications of the Smithsonian Institution.

Col. Whittlesey returned to military life in 1861, and served as State Military Engineer for Ohio volunteers, and afterward as Colonel. He was born in Southington, Conn., and died in Cleveland, Ohio, which had long been his home.

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